EFFECT OF DAYLIGHTING ON ENERGY CONSUMPTION AND DAYLIGHT QUALITY IN AN EXISTING ELEMENTARY SCHOOL

A Thesis

by

UMESH VINAYAK ATRE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2005

Major Subject: Architecture

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Approved as to style and content by:

Mark J. Clayton (Chair of Committee)	Jeff S. Haberl (Member)
John A. Bryant (Member)	Phillip J. Tabb (Head of Department)

May 2005

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ABSTRACT

Effect of Daylighting on Energy Consumption and

Daylight Quality in an Existing Elementary School Building. (May 2005)

Umesh Vinayak Atre, B.Arch, University of Mumbai

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This research investigates the effects of daylighting in an existing elementary school in College Station, Texas. The conclusions are generalizable to similar school designs in hot and humid climates. This study focuses on the trends observed in the building's heating, cooling, and lighting energy consumption due to daylighting, and the overall effect on total energy consumption. Skylights with 1% to 10% glazing surface to floor area and clerestories from 2 ft to 8 ft glazing height were analyzed to formulate balanced daylighting designs that could provide for decreased electricity and gas energy consumption and increased daylight illuminance levels and energy cost savings.

Classroom and Library areas inside the case study school building were analyzed using walk-throughs and daylight factor measurements to understand existing lighting conditions and the potential for daylighting. Physical scale models of the study spaces with and without daylighting alternatives were built for daylight factor and daylight penetration analysis. Computer simulation models were created for the base case and all proposed daylighting designs for building energy performance evaluation using the DOE-2 building energy simulation program. Daylight factors from the actual spaces, physical model measurements, and computer simulation outputs were studied for trends in interior daylight illuminance levels. Annual energy consumption analyses were performed using DOE-2 and involved heating, cooling, and electrical energy use comparisons of all proposed designs with the base case. One design each from the skylight and clerestory cases, and an overall design based upon the performance criteria are proposed for the existing school building. The building energy analyses suggested that a considerable reduction in artificial lighting and total electricity use could be achieved through proper sizing of skylights and clerestories. Heating energy use stayed almost constant in all cases. Considering all different trends in energy use, all the proposed cases perform better than the base case in terms of total energy savings. The spaces analyzed constituted 15% of total school area, and projected savings would be much higher if daylighting could be applied to the entire school building.

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CHAPTER I

INTRODUCTION

This research investigates the effect of daylighting on the energy consumption of an existing elementary school in College Station, Texas. The school building studied is typical of a one-storied elementary school and the research is generic to school buildings with similar construction style, located in similar climates and social cultures. This research studies the potential of daylight as a natural renewable source of energy in providing for the required illumination requirements in a typical school building. It is an attempt to portray daylighting as an economical and healthy solution to replace artificial lighting and save energy. This chapter comprises a brief summary of world energy statistics and United States energy statistics, followed by an introduction to commercial and educational energy usage in the United States. It states the purpose of this research, scope of study, and gives a short account of the methods used in research. This introduction ends with a summary of all the chapters in this thesis.

1.1. BACKGROUND

According to the official Energy Information Administration (EIA) statistics, world population has recorded an increase from 5,415 million in 1992 to 6,145 million

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This thesis follows the style and format of *ASHRAE Transactions.*

in the year 2001, which indicates a 11.87 percent total increase, and annual average increase of 1.3 percent (EIA 2003). The rising population count has a detrimental effect on the limited and constantly decreasing natural energy resources. Between 1992 and 2001, the world's total output of primary energy - petroleum, natural gas, coal, and electric power (hydro, nuclear, geothermal, solar, wind, and wood and waste) - increased at an average annual rate of 1.5 percent (from 351 quadrillion (10^{15}) Btu in 1992 to 403 quadrillion Btu in 2001). In 2001, the United States, Russia, and China - were the leading producers and consumers of world energy, producing 38 percent and consuming 41 percent of the world's total energy (EIA 2003). Renewable energy sources have been neglected sources, with Hydro, nuclear, and other (geothermal, solar etc.) power generation accounting for a meager 6.62, 6.56, and 0.8 percent, respectively, of world primary energy production.

1.2. U.S. ENERGY STATISTICS

The U.S. population has increased from 149 million people in 1949 to 281 million in 2000, denoting an increase of 89 percent, while the total energy consumption grew from 32 quadrillion (10^{15}) Btu to 98 quadrillion Btu (up 208 percent). But when population and energy consumption is compared, the efficiency with which Americans use energy today has improved over the years. Efficiency improved 49 percent between 1949 and 2000; the amount of energy required to generate a dollar of output fell from 20.6 thousand Btu to 10.6 thousand Btu (EIA 2003).

Most energy produced today in the United States comes from fossil fuels-coal, natural gas, crude oil, and natural gas plant liquids In the year 2000, they accounted for 80 percent of total U.S. energy production, with other sources including renewable sources, accounting for the remaining production (EIA 2003). Figure 1.1 shows an overview of the energy consumption and production trend from 1949-2003 (EIA 2003).

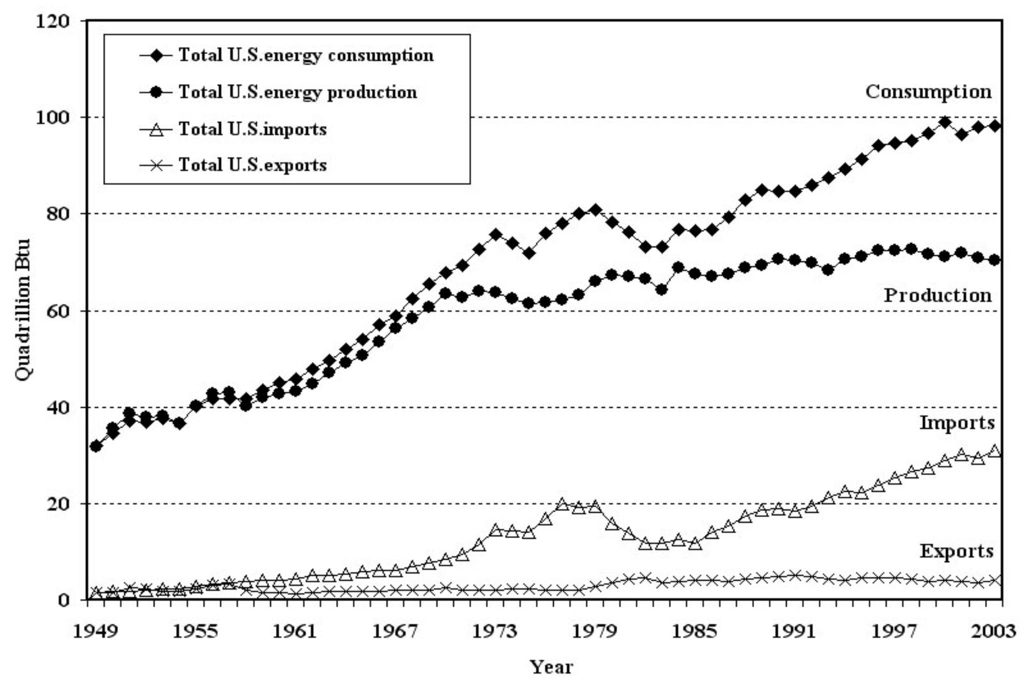


Figure 1.1 – Energy overview (EIA Report, Annual Energy Review 2003)

1.2.1. Commercial Energy Consumption

According to EIA statistics, commercial buildings in the U.S. used a total of approximately 5.7 billion Btu of all major fuels (electricity, natural gas, fuel oil, and district steam or hot water) in 1999. Electricity consumption is projected to increase in all the end-use sectors. The highest growth rate is projected for the commercial sector, at 2.2 percent per year from 2002 to 2025, compared with 1.6 percent for industrial and 1.4 percent for residential electricity demand. Electricity accounted for 76 percent of commercial primary energy consumption in 2002, and its share is projected to increase to 79 percent in 2025 (EIA 2003).

1.2.2. Educational Energy Consumption

In many school districts, energy costs are second only to salaries, exceeding the cost of supplies and books. Nationally, K-12 schools spend more than $6 billion a year on energy and, according to the U.S. Department of Energy, at least a quarter of that could be saved through smarter energy management. Energy improvements could cut the nation's school bill by $1.5 billion each year (EERE 2003). According to the EIA CBECS (Commercial Buildings Energy Consumption Survey), educational buildings used 649 trillion Btu of total energy, which was 11 percent of total energy consumption for all commercial buildings.

The typical school district spends $400,000 each year on utility bills while those in huge metropolitan areas may spend $20 million or more. Most schools can save 25 percent of these high costs by being smart about energy. In the typical district, that would amount to about $100,000 in savings each year (EERE 2003). While improving their energy use in buildings, the schools are likely to create better places for teaching and learning, with better lighting, temperature control, acoustics, and air quality. Energy-efficient improvements can lower a school district's utility bills and maintenance expenses, and can enable the district to save towards other expenses. Recent studies show that daylighting in schools may significantly increase students' test scores and promote better health and physical development and can be attained without an increase in school construction or maintenance costs (NREL 2000).

Beyond the impact of higher quality school settings on learning, there are more extensive potential benefits to personal health and society.

> Children breathe higher volumes of air relative to their body weights and are actively growing. Thus, they have greater susceptibility to environmental pollutants than adults. Children also spend more time in school than in any other indoor environment outside the home. Adverse environmental impacts on the learning and performance of students in schools could have important immediate and lifelong effects, for the students and society. (Heath and Mendell. 2002)

1.3. INTRODUCTION TO THE PROPOSED RESEARCH

The research has been divided into four stages. The first stage will involve the contextual representation of the research. Since the research is generic to the College Station climatic type, a detailed documentation of the study climate will be presented. The American cultural scenario and the corresponding school facility requirements will be described to define the context of this study.

The second stage involved inspection of the site and buildings, and procurement of all the relevant construction data, schedules, and mechanical systems information for the school building. Using the building data and school statistics, a computer simulation model was created using the DOE-2.1E simulation program. DOE-2 is an up-to-date, unbiased computer program that predicts the hourly energy use and energy cost of a building, given hourly weather information, and a description of the building and its HVAC equipment and utility rate structure (LBL 2002). The measured energy consumption for the school, as provided by the school district were compared with the simulated results for similar time frames and weather conditions. The simulation model will serve as a base case for evaluation of daylighting alternatives.

The third stage was the study of the classroom spaces that are selected for analysis through the use of a physical model. The physical model was built to a scale of 1 in. per ft. for ease in lighting measurements and photography analysis. At this scale, critical daylighting details can be evaluated in accordance with the building's desired performance (Ander 1995). The model has a flexible roof structure that was modified to experiment with different types of skylights and orientations. Daylight factors were measured in the model at different times of the day and under overcast and clear sky conditions. These measured coefficients were compared with the corresponding values as calculated by the simulation program, DOE-2. This comparison was used to confirm the validity and reliability of the values.

The fourth stage was an analysis of the daylighting parameters in the LOADS portion of the DOE-2 simulation input file. Different configurations of skylights were analyzed for their effect on the lighting energy consumption, cooling and heating loads on the building under consideration. This has provided a better understanding of the specific input parameters required for the study of daylighting and their effects on the building energy consumption.

The school under consideration is one of the five elementary schools under the College Station Independent School District (CSISD) administration. College Station Independent School District is located in College Station, Texas. The Energy Systems Laboratory (ESL) at the Texas A & M University has prepared electricity baselines for the CSISD as part of the 'Rebuild America' Program. The electric consumption for each school has been obtained by the Energy Systems Laboratory from the monthly utility bills, whereas the monthly average dry-bulb temperature has been obtained from the LoanStar Database for College Station, Texas (ESL Report 2001). This information will be used as reference data during the proposed research.

The concept of daylighting was studied in relation to the lighting requirements in a typical classroom module in the school. This study concentrated on the availability and feasibility of natural light usage as compared with artificial light in the classrooms of the school building. The factors considered under this aspect of the study included studying the position and size of skylights, and thermal comfort conditions in the spaces. The suggested retrofits will maintain a balance between aesthetics and energy performance.

1.4. PURPOSE OF RESEARCH

The purpose of the research is to investigate the energy consumption in an elementary school in College Station, and develop recommendations for architectural design for similar facilities in similar cultures and climates. Top-lit daylighting solutions have been experimented through the use of building case study, physical models, and computer simulations, and optimum design guidelines are suggested. This research aims to establish a comparison between daylighting and energy consumption in a typical elementary school building.

1.5. SCOPE OF RESEARCH

The research is generic to all elementary school buildings in the United States that experience a hot and humid climate similar to the city of College Station, Texas. The increase in energy costs and a likelihood of even higher future prices threatens our communities. Few areas of our social pattern of life are as seriously affected as schools. An individual school's energy consumption is intricately linked with the total community's energy consumption as well (Neill 1977).

For the purpose of this research, an elementary school in College Station has been selected as a base case. This school is representative of a typical one-storeyed elementary school in a hot and humid climate. The study assumes that the school energy consumption data is accurate and does not account for any discrepancies involved with faulty data logging equipment, if any. As a case study of a single school, care must be taken in interpreting conclusions and applying them to other schools. Climate considerations will also limit the conclusions. Because latitude affects sun angles, conclusions must be limited to similar latitudes. Usage patterns and cultural factors are also expected to be significant. Results should not be generalized beyond the culture. The area of research is directly important to school administrators and energy planners/design faculty at the local and state level, all of which have an active interest and responsibility in the school's physical functionality. This is ultimately important for the overall physical and psychological development of the end-user – the student.

1.6. SUMMARY

This study has been documented into Chapters I-VI. The next chapter documents the literature review conducted for this research. It includes a review of past studies published in journals, books, theses and dissertations, and verified documents from literature research websites that are relevant to this research. The third chapter explains the methodology used for this research, including the various stages involving visits to the case study school building, physical model construction and analysis, and use of the DOE-2 energy simulation program for energy and daylighting evaluations. The DOE-2 base case model calibration has been discussed in Chapter IV. Various calibration tools involving graphical and statistical techniques have been presented for monthly, daily, and hourly model calibration. Chapter V explains the results of the daylighting and energy use analyses, and concludes with an evaluation of energy savings and energy cost savings as can be realized through the proposed daylighting cases. The two daylighting options proposed and studied are the skylight and clerestory methods of introducing daylight into interior spaces. Chapter VI suggests future work that can be conducted in this area of research, and provides recommendations based on conclusions. All references used in this research have been documented at the end of the chapters, and the base case DOE-2 input file with selected daylighting inputs have been documented in the appendices.

CHAPTER II

LITERATURE REVIEW

This chapter provides an overview of the literature related to this research. This study relies upon extensive research carried out over the past several decades. Because of the large amount of research in this field, the literature review is not comprehensive, but is extensive. This literature focuses on areas including climate of Texas, lighting in buildings, daylighting in schools, building energy consumption, energy consumption in institutional buildings, building energy simulation tools, and the DOE-2 energy simulation software and its specific application to daylighting analysis.

The main literature sources used by the researcher for the above-mentioned topics were:

- LBNL Publications and research reports
- USDOE and EIA Statistics and reports
- ASHRAE Transactions
- Proceedings of the International Daylighting Conference
- Symposium on Improving Building Energy Efficiency in Hot and Humid Climates
- Energy and Buildings Journal
- Energy Journal
- Renewable Energy Journal

- Energy and Buildings Journal
- Building and Environment Journal

Other than these mentioned sources, literature was also acquired from published books and magazines, previous theses and dissertations, and various online sources related to the area of concentration.

2.1. CLIMATE OF TEXAS

2.1.1. Location

Texas' range in latitude (from 26 deg. N in south to 36 deg. N in the north) places it on the equatorial side of the mid-latitude regions. It receives a large amount of insolation. The Gulf of Mexico has a profound bearing upon the weather throughout Texas - and especially in the coastal plain - because prevailing winds for much of the year blow from the sea onto the land (Bomar 1983). The state of Texas lies in the Temperate Zone of the Northern Hemisphere, and experiences three main climatic types: Continental, Mountain, and Modified Marine (Larkin and Bomar 1983).

2.1.2 General Weather

Texas is close to the Tropic of Cancer, and experiences hot summers. The vertical sun rays towards the summer solstice period make the land very hot and temperatures soar. Texas climate is characteristic of mild to warm muggy nights and repressively hot days (Bomar 1983). Typical midsummer temperatures range between 70 and 90 degrees farenheit throughout the state (Norwine et al. 1995). Humidity levels are generally high in the mornings and level out towards the later parts of afternoon.

2.1.3. Climate of the Brazos County (College Station, Texas)

Brazos County is located in the Central and East part of Texas, and experiences climate similar to the state of Texas as a whole. This part of Texas is subjected to hot summers; heavy rainfall accompanied by thunderstorms, gusty winds, and might also experience an occasional hurricane (Norwine et al. 1995).

2.1.3.1. Temperature and Humidity

The location on the equator-ward side of the mid-latitudes is one of the main controlling factors of the diurnal and seasonal temperature distribution, and this makes the climate highly diverse. Large day-to-night (diurnal) temperature variations are a character across this part of Texas. “Morning minimum temperatures, and afternoon maximum readings, may vary among themselves from day to day only a few degrees over many weeks during the summer” (Norwine et al. 1995, pp. 82). This region experiences hot summers and relatively cool and humid winters. Sultry conditions prevail during the summer in the entire region, and spells of high humidity occur often in other seasons as well, even in winter. Humidities are higher early in the day and usually bottom out during the afternoon and early evening. “Typical relative humidity in the Dallas-Forth Worth area in summer ranges from 80 percent at dawn to 44 percent in late afternoon” (Norwine et al. 1995, pp. 88).

2.1.3.2. Rainfall

The Gulf of Mexico is the primary reason for high humidity levels and rainfall patterns in this region; it is the source of the bulk of atmospheric moisture entering the state. The Brazos County region receives at least 40 inches of rain in a typical calendar year (Norwine et al. 1995).

2.1.3.3. Winds

A mild to high southern and southeastern airflow from the Gulf of Mexico and Chihuahuan Desert is particularly marked during the summer, while northerly winds flow in winters (Norwine et al. 1995).

Due to the year-round presence of bright skies, the Central and East Texas region becomes an ideal region for the application of daylighting principles in buildings.

A study of the general climate of Texas and the specific climate of the Brazos County indicate abundant annual availability of sunlight. College Station, located in the Brazos County is thus an ideal location to study daylighting in buildings. Though daylight availability is a positive factor for daylight studies, the presence of high humidity and rainfall suggest a concern towards moisture problems and leakages in top-daylit solutions like skylights and clerestories.

2.2. LIGHTING DESIGN

2.2.1. Light

"It is possible to trace the roots of the meaning of light back to early civilization and before. Through the evolution of man, light is associated with safety, warmth, and community (Baker and Steemers 2002, pp. 4)." According to the Illuminating Engineering Society of North America (IESNA) Lighting Handbook (1984), light can be defined as '*the radiant energy that is capable of exciting the human retina and creating a visual sensation*', with Lighting Design being defined as '*the creative process to produce lighting methods and solutions for safe, productive, and enjoyable use of the built environment, utilizing available illuminating engineering technology.*' Natural light in the form of sunlight is a powerful source with an average illuminance of 1600 megacandelas per square meter, as viewed from the sea level (IESNA 1984, pp. 2-6).

2.2.2. Interior Lighting

Hathaway (1995) describes the availability and usage of natural lighting thus: "Sunlight is by far the most important source of light and energy for living organisms, and it may be experienced as direct light or as skylight (diffused light). Most people spend part of each day under the influence of sunlight. However, as society becomes more urbanized, people spend much less time under sunlight and much more time under artificial lamps" (Hathaway 1995, pp. 228). The IESNA has further described general and specific lighting guidelines to facilitate lighting design in the building interiors. A design procedure recommended by the IESNA incorporates four steps: defining visual tasks in the proposed design, selection of illuminance category, determining the amount of lighting required, and establishing a target illuminance value for design (IESNA 1987).

The following two tables are part of the IESNA recommended illuminance categories and illuminance values for interior lighting design and target light levels. Table 2.1 defines the illuminance categories and respective values, whereas Table 2.2 relates the activity type with specific illuminance category as defined in the earlier table.

Table 2.1 -Illuminance categories and illuminance values for lighting: Generic types of activities

Type of activity	**Illuminance Category**	**Ranges of Illuminances**	
		Lux	Footcandles
Visual tasks of high contrast or large size	D	200-300-500	20-30-50
Visual tasks of medium contrast or small size	E	500-750-1000	50-75-100
Visual tasks of low contrast or large size	F	1000-1500-2000	100-150-200

(Source: IESNA Lighting Handbook 1987, pp. 2-5).

Table 2.2 -Recommended illuminance categories for institutional interiors

Educational Facilities	**Illuminance Category**	**Average selected value**	
Classrooms		Lux	Footcandles
General / Drafting / Science Labs	**E**	**750**	**75**
Lecture rooms / Audience / Demonstration	F	1500	150
Music rooms / Shops / Study halls / Typing	F	1500	150

(Source: IESNA Lighting Handbook 1987, pp. 2-5 – 2-21).

The type of activity in classroom-like spaces generally involves visual tasks of medium contrast or small size (category E), and IESNA suggests the use of this category for educational facilities like elementary schools. The average illuminance value selected for daylighting analysis in the proposed research is between 50 to 75 footcandles. The top-daylighting options suggested should focus on achieving this range of illuminance in the analysis spaces.

2.3. DAYLIGHTING

2.3.1. Defining Daylight and Daylighting Systems

Daylight is the combination of the diffused light from the sky and sunlight (Baker and Steemers 2002). For centuries, daylight was the only efficient source of light available. Historically, building openings had to be so designed as to allow enough daylight penetration into interior spaces (IEA SHC Task 21 2000). With the scientific advance in the field of light, artificial lighting systems were invented, and designers occasionally neglected importance of daylighting. Today, awareness of depleting non-renewable natural resources has again brought the potential of the use of natural light (daylight) in building design to the attention of many designers.

Hopkinson et al. (1966) termed daylight as a gift of nature, and stressed the importance of the special advantages of daylighting. As stated by Ander (1995), “the relationship between people, daylight, and architectural form is intimate.” Daylighting has always played an important role in the design of buildings, and research indicates the various psychological advantages of the use of daylight in building design.

A daylighting system, as defined by Baker and Steemers (2002, pp. 242) is “a device located near or in the openings of building envelope, whose primary function is to redirect a significant part of the incoming natural light flux in order to improve interior lighting conditions.” Today, advanced daylighting systems can provide daylit, user-friendly, and energy-efficient building environments.

2.3.2. Daylight Source and Availability

The sun is the source of natural light energy and the path of the sun determines the available sunlight at a particular building location. The *solar altitude* and the *solar azimuth* are the two angles through which the sun’s position can be defined at a reference point on earth’s surface. The Overcast sky, Clear sky, and Partly cloudy sky are three light conditions to be considered in daylighting design, according to the *IESNA Lighting Handbook* (IESNA 1984).

“Daylight availability is the amount of daylight available from the sun and the sky at a specific location, time, date, and sky condition” (IESNA 1984). The sun, sky, buildings, and ground are the main sources of luminance distribution. Latitude, climate, and building orientation affect daylight availability, and hence need to be studied to design for daylight (IEA SHC Task 21 2000). Daylight availability data is recorded every minute at more than 50 stations across the world.

The daylight availability data from the Houston TMY2 weather file will be used in the proposed research to determine typical days for daylighting analysis, depending on direct and diffuse solar radiation.

2.3.3. Daylight Calculations

Qualitative information and quantitative figures reflecting the engineering aspect of daylighting design are both equally important to a lighting designer (IEA SHC Task 21. 2000). During the last half of the nineteenth century, daylight calculation methods from natural sources first became available (Ander 1995). A number of calculation methods are used for daylight computation. These include the Lumen Method for toplighting and sidelighting (IESNA 1984), Computation of Illuminance (IESNA 1984), Graphic Daylighting Design Method (GDDM) (Stein and Reynolds 1999), and the Daylight Factor Method (Hopkinson et al. 1966). The Lumen Method and the Daylight Factor Method are the most widely used.

The *Daylight Factor* is the "illuminance received at a point indoors, expressed as a percentage of the total horizontal illuminance outdoors from an unobstructed illuminance of the same sky" (IESNA 1984). Direct sunlight is excluded from both interior and exterior values of illuminance (Baker and Steemers 2002). The daylight factor method will be used for daylighting calculations in the proposed research to compare the effect of proposed top-daylighting solutions in the existing school building. Daylight factors will be compared using actual space measurements, values from a physical model, and daylight factors calculated by the DOE-2 simulation program.

2.3.4. Daylighting Analysis

Daylight has not been a very important design factor for the past decade (Johnsen 1998). Modern buildings have often disregarded the potential of daylighting. According to Johnsen, the three basic reasons for this attitude towards daylighting was the lack of knowledge and information on new fenestration technologies, lack of convincing evidence that daylighting could improve energy efficiency and enhance visual quality inside spaces, and the lack of appropriate and user friendly daylighting design tools (both physical and computer). "The combined reduction of lighting energy use, cooling energy use, and peak energy use that often results from daylighting can reduce the total energy cost of a commercial building. These various reductions in cost establish the energy cost differential, which is used to determine the cost effectiveness of the daylighting solution" (Robbins 1986).

Various daylighting systems were listed by Kischkoweit-Lopin (2002), and their properties were defined using a system matrix. The system matrix divided the systems into two basic principles: shading systems and optical systems. Shading systems were further classified as those using diffuse sunlight (for example, prisms and venetian blinds), and those using direct sunlight (for example, a light shelf). Optical systems were classified into: diffuse light guiding systems (for example, anidolic ceiling), direct light guiding systems (for example, laser cut panels), scattering systems (for example, capillary glass), and light transport systems (for example, light pipes / tubes).

Bodart and De Herde (2002) regard the reduction of the fossil combustible stock as well as the irreversible damage caused by their combustion as one of the biggest topical earth problems.

> For many researchers, taking into account the daylighting can not only allow an artificial lighting consumption reduction, but also a reduction of the lighting internal loads and thus of the cooling loads. However, the winter heating

consumption will increase and the admission of too much daylight introduces solar heat gains that can increase cooling loads associated with the window systems. There is an optimum cooling, heating, and lighting energy balance that can only be reached by an integrated approach combining the daylighting and the thermal aspects (Bodart and De Herde 2002, pp. 421-429).

2.3.5. Use of Physical Scale Models

Scaled building models are extensively used for daylighting design. If a scaled model is an adequate representation of the real space, and is tested under similar sky conditions, it will yield results identical to the real building space (Ander 1995). Different model scales are used, ranging from 1/8 inch per 1 foot for small massing study models, to 1 inch per foot to full-scale mock-ups for very detailed analysis (Ander 1995).

2.3.6. Daylighting and Student Performance

Access to daylight can positively affect human performance. “The extent to which unsuitable lighting also impairs health and well-being is now the subject of a large-scale investigation carried out in numerous companies by the Berlin Ergonomic Institute for Industrial and Social Research. However, the positive effect of daylight cannot be replaced by anything” (Cakir and Cakir 1998).

The Heschong Mahone research team (1999) analyzed standardized math and reading test scores of more than 21,000 elementary school students from the three districts of Orange County, CA, Seattle, WA, and Fort Collins, CO for over one year.

California students with the most daylighting showed a progress of around 20-26 percent in their test scores over the entire year, while Seattle and Fort Collins students reported an increase of 7-18 percent at the end of the year (Heschong Mahone Group 1999).

Another study based itself on the earlier daylighting and student performance studies conducted by the Heschong Mahone Group (2002). Using multiple regression analysis, more than 8,000 students from 450 classrooms were analyzed in their academic performance. A detailed analysis was also made of the effect of factors like indoor lighting, windows, views and other room factors on the student performance. Pleasant views from windows were found to affect students positively, whereas glare, direct sun penetration, and negligence to window control and shading were shown to affect student performance in a negative manner. The two studies by the Heschong Mahone Group are significant in establishing that daylighting has a direct effect on student performance. Though these studies do not take into consideration factors like study methods and other individual school statistics, they suggest the role of daylighting, presence of windows and views, and an overall comfortable studying environment to positively affect student performance. A similar kind of study though not within the scope of the proposed research, nevertheless validates use of daylighting in schools.

Nicklas and Bailey (1995 a) from *Innovative Design* analyzed the performance of students from three schools in Johnston County of North Carolina. All three were daylit schools, designed by *Innovative Design*. From 1987/88 through 1991/92 the average total battery test scores were compared for students from these schools. After 1991/92 the average of the reading and math components of test scores was used to compare performance. The comparison was made between the performance of all other County schools, and students attending new, daylit schools performed 5-14 percent better than students from non-daylit schools. Also, a temporary shift to mobile classroom units during the new schools construction phase showed a negative effect on performance, with the average CAT scores dropping from 7-10 percent below the normal average for the County. This study is similar to the earlier mentioned Heschong Mahone study, except that the analysis period was more (around 4 years) in this case, and focused on comparison between different schools in the same county. This study further establishes the fact that daylighting can positively affect student performance, and hence can be an important design recommendation.

According to Heath and Mendell (2002), “children spend more time in school than in any other indoor environment outside their homes. Adverse environmental impacts on the learning and performance of students in schools could have important immediate and lifelong effects.” A study by Heath and Mendell (2002) reviewed available literature to confirm evidence on the effect of indoor environmental quality (IEQ) problems on student performance in U.S. schools. The results showed that some IEQ problems, including poor daylighting and ventilation did affect occupant performance (Heath and Mendell 2002). Another important study, by Sammaljärvi (1991) focused on effects of IEQ factors like dust, heating, stuffy air, and room embellishment on the physical health of children. Bad indoor air quality and dust alone caused most of the health problems (mainly respiratory) in children. These two studies indicate the importance of a daylit and effectively ventilated indoor environment on children’s health and performance. Daylighting is found to be an important contributor to indoor environmental quality.

Hathaway (1995) studied the effect of different types of artificial lighting systems on the physical development and overall school performance of elementary grade students. Sufficient evidence from the results indicate that students under a particular type of lighting system maintained better physical health, showed better academic performance and had more attendance at their schools as compared to other students exposed to a different kind of lighting. Good lighting was shown to have a direct effect on student performance. This study provides validity to the proposed research.

Wei (2003) studied a sample population of 1330 students from 35 classrooms in 8 secondary level schools in Hong Kong to understand the exact quality and quantity of daylight in schools located in high-density urban landscapes. Student and teacher satisfaction (post-occupancy evaluations) with their respective classroom natural lighting was judged as one of the criteria to assess daylighting quality. Qualitative analysis included survey questionnaire and interviews with students and teachers, while quantitative analysis was based upon walkthrough, visual perception of defects, photometric measurements, photography, and a review of building drawings and construction documents. Other than spatial design and material properties like reflectivity and glare problems, the ‘total daylighting quality’ was attributed to classroom orientation, position in the urban fabric, and most importantly, user attitudes.

The study by Dunn *et al*. (1985) reviewed past research and literature on the effect of lighting on student performance and character, and confirmed the fact that good lighting (daylighting and artificial) can contribute immensely to the psychological and physical well-being of a student. Students were shown to achieve better when tested in rooms with the required footcandles of light, in contrast with their scores in low, dimly lit rooms. A study in Industrial Psychology by Cakir and Cakir (1998) studied the 'stress factor' among the working population in the Federal Republic of Germany. As part of a research study at the Ergonomic Institute in Berlin, over 2,000 office-goers were analyzed over several years for lighting-related health problems, and it was found that more than 50 percent of the persons attributed their health defects to improper office lighting conditions. These studies show the importance of daylighting not only on the psychological but also the physical well-being of an individual. This part of the literature review helped in gaining an insight into various effects of daylighting other than reducing building energy use.

2.3.7. Windowless Classrooms and Student Behavior

Heerwagen and Heerwagen (1984) conducted studies at the University of Washington involving occupant responses to heat reflective glass, windowless spaces, and presence of discomfort glare. Data was collected through unobtrusive observations concerning the availability of windows, position of window from occupant, full window views, wall display material, and interesting views or content outside windows. Preliminary output indicated that subjects kept in windowless spaces tried to adapt themselves virtually to the outside environment through more displays of nature photographs and posters than people in the windowed space. Tognoli (1973) experimented with a group of 56 human subjects to understand the psychological effect of windowless spaces, room furniture types, and embellishment. Subjects were placed in two experimental rooms, one of which was windowless, and were administered a small verbal material retention questionnaire and an attitude-based rating system for different space characteristics. The subjects rated the presence of window as being more pleasant, and response to other room embellishments indicated that windowless spaces created a negative feeling and mental discomfort.

Karmel (1965) examined the effect of windows versus windowless classrooms on students' drawings. A total of 1,217 high school students were asked to draw a complete picture of their schools. An expert review of the drawings by three well-known psychologists revealed that students from windowless classrooms drew windows more than those from windowed school classrooms. Evidence indicating hostile nature, psychopathology, and negative feelings for their school was also found through the drawings of students from windowless classrooms. These earlier studies by Heerwagen and Heerwagen (1984), Tognoli (1973), and Karmel (1965) indicate that human subjects prefer natural light and windows in spaces, and concur with the recent study by Wei (2003).

Heerwagen and Heerwagen (1984) suggested "it was reasonable to expect that windowless environments may be more stressful and psychologically uncomfortable than windowed spaces." 350 students from northern England primary schools were studied by Stewart (1981) for their behavior and attitudes towards their visual environment, with particular attention to factors associated with fenestration and daylight in the schools. It was seen that more than 70 percent of the children chose to sit close to the window (if given a free choice), thus preferring higher daylight levels.

Extensive literature by Boyce et al. (2003) considered the impact of daylight on human performance and workplace productivity, human health, and financial return on investment. A 1995 U.S.GPO (USGPO 1995) report stated that "nearly 60 percent of U.S. schools reported at least one major building element in disrepair; most of these schools had multiple problems." Earthman et al. (1995) surveyed 199 high schools in North Dakota to establish a relationship between student performance and behavior to the physical condition of their school buildings. Buildings were classified as being above standard, standard, and below standard, depending upon their respective conditions. It was found that students from above standard schools performed much better than substandard school students. No specific relation was found to exist between student behavior and building condition.

2.3.8. Summary

This review was helpful in understanding the basic principles of daylighting in buildings. The climate of College Station is ideal to study effect of daylighting. The proposed research might be applicable to other parts of the United States that experience similar climates. Daylight design has gained attention during the past decade, and various daylighting analysis methods are available for researchers. The daylight factor method was found to be an efficient indicator of daylight quantity in spaces, and will be used in the proposed study. Scaled physical models can be used to evaluate the various proposed options to be studied for the proposed research. Daylighting can reduce internal lighting loads, thus reducing the total electricity use in a school building. Efforts should be taken to balance the quality of daylight and thermal aspects in this research. Previous studies indicate a positive effect of daylighting on human performance, productivity, and attitudes, with specific indications of improved student performance in schools, which gives added validity to the proposed research.

2.4. BUILDING ENERGY SIMULATION

"Dramatic improvements in computing power, algorithms and physical data make it possible to simulate physical processes at levels of detail and time scales that were not feasible only a few years ago" (Hensen and Nakahara 2001).

Augenbroe (2002) gives a short account of the characteristics of the building simulation tools currently used by the industry, and comments on the immediate and long-term goals of new simulation tools for a more efficient and time-effective design analysis. Rapid evaluation of alternative designs, design as a (rational) decision making process, explicit well-posedness guarantees, and new solvers for nonlinear, mixed and hybrid simulations have been termed as some of the 'new' tool wishes for the future. The Internet has been termed as the ultimate work-sharing platform for building simulators. Kusuda (2001) describes the changes that the field of building energy simulation underwent from the early 1950's uptil the current date. The paper presents an account of earlier computer simulation programs and the evolution of the programs like BLAST and DOE-2, which are now extensively used in the industry. It also gives a detailed explanation of various organizations and symposia that were established to explore the use of computers for environmental engineering. The proposed research uses the DOE-2.1e (version 119) building energy simulation program, the roots of which have been explained in this paper by Kusuda (2001).

2.4.1. Energy Performance in Academic Institutions

According to statistics presented by Plympton et al. (2000) from the National Renewable Energy Laboratory (NREL 2000), "between 2000 and 2007, at least 5,000 new schools will be designed and constructed to meet the needs of American students in kindergarten through grade 12 schools."

There are numerous aspects of daylight that makes its use in educational facilities desirable as a light source and valuable both psychologically and esthetically. With rising energy costs, daylight must be considered to be an important source when planning new buildings or retrofitting old ones (IESNA 1987). "Approximately 5 percent of the United States' primary energy is consumed providing illumination in commercial and industrial buildings. It is possible for sunlight to decrease the electric lighting illumination levels required to achieve a satisfactory luminous environment" (Wayne et al. 1984). School energy consumption has been widely researched and indicates a trend towards building more energy-efficient schools, with a focus on daylighting in particular.

Wong and Jan (2003) assessed the Total Building Performance (TBP) of two building blocks in a typical secondary school in Singapore. The analysis involved both objective and subjective evaluation through the use of techniques like walk-through, visual inspections, data logging, and on-site information processing. Tools like interviews, questionnaires, surveys, and recording instruments were used for subjective data analysis. Thermal, lighting, indoor air quality, spatial, and acoustic requirements were studied for both the building blocks using building energy codes and environmental guidelines, and were applied as base comfort levels. Temperatures and humidity levels inside the classrooms were found to be higher than the recommended maximum, and the illuminance values were lower than the recommended 500 lux, with a problem of glare near windows. Carbon dioxide levels were found to be within the recommended maximum, but still on the higher side. Acoustic and spatial values did not fit within the recommendations. The subjective analysis tallied with the objective results for one block, and was completely positive (complete acceptance of existing conditions) for the other block. The results are preliminary in nature, but are a good starting point in total school building analysis. Some of the methods used by Wong and Jan (2003), including walk-throughs, visual inspections, and daylight measurement instruments will be used in the proposed research to analyze existing lighting conditions inside the classrooms.

The goal of educational facility lighting should be to provide an optimum visual environment for students and instructors alike. Uniformity in lighting systems throughout the educational facility does not assure optimum visual performance in every area because of the great variety of visual tasks found in any school situation (IESNA 1987).

Wong and Khoo (2003) studied thermal comfort conditions inside ceiling-fan ventilated classrooms in Singapore. Objective analysis carried out using ASHRAE Std. 55 comfort condition charts and data showed that none of the classrooms were within acceptable comfort conditions. Subjective analysis through surveys concurred with the objective results. The ASHRAE standard was found unsuitable for the non-air conditioned classrooms in a hot and humid climatic setting. Thermal comfort conditions within the classrooms were analyzed using the ASHRAE scale, Bedford scale, votes of preference and direct votes of acceptability, and acceptable values for the indoor environment were determined. Recommendations like solar shading and air-conditioning were suggested in order to present acceptable levels of air quality and temperature. This study explains an objective analysis method, and a similar objective analysis will be conducted for the proposed research using IESNA standards for daylight quantity inside classrooms.

Milan and Pattison (1980) studied the thermal environment of a primary school building that was designed as a departure from the normal post-war type schools. This building, square in form to reduce enclosed space, had a heavy wall construction of 200 mm thick monolithic load-bearing panels, and the external glass area was just 20 percent of the total wall surface, as against the then prevalent curtain wall glazing systems. Temperature variants and humidities recorded at different places in the school indicated a stable indoor comfort condition for most part of the year. Peak effects of solar radiation were also delayed until after school hours due to the heavy construction type. Glazing area will be an important consideration in the proposed research, with different sizes of skylights and clerestories being proposed as daylighting options. A balanced design that achieves recommended daylight levels with decreased energy use would be proposed.

Various case studies represent the increasing interest in design of energy-efficient institutional buildings. Nicklas and Bailey (1995 b) evaluated the first year energy performance of three new daylit schools, Clayton and Selma Middle Schools and the K-5 Four Oaks School designed by Innovative Design. These schools were compared to with similar but non-daylit schools in their respective Counties in North Carolina. Annual energy consumption was also compared with two other daylit schools designed by the same firm. All schools were prototypical in their daylighting design, incorporating south-facing roof monitors, except one which had both south and north roof monitors, and all schools proposed to achieve daylighting levels over 70 fc (~ 700 lux) in classrooms. The cost of added daylighting construction features was high, but was offset due to downsizing of mechanical and electrical systems. Energy consumed by the newly built schools, though included energy used for criteria like computers, advanced AV equipment and extensive evening use of gymnasiums, still indicated total annual energy cost reductions from 22 percent to 64 percent over the existing schools. This study is relevant as the proposed research aims at developing energy-efficient daylighting solutions for school buildings.

2.4.2. Summary

Subjective and objective studies by Wong and Jan (2003), and Wong and Khoo (2003) indicate the insufficient daylighting and other thermal comfort conditions in existing school spaces. The proposed research aims at improving existing lighting conditions in the school building under analysis using walk-throughs, space light measurements, and computer simulation. Milan and Pattison (1980) indicate importance of glazing and building materials in reducing energy consumption, and this factor forms an important part of the proposed analysis. The study by Nicklas and Bailey (1995 a) was simultaneously conducted during their other study involving effect of daylighting on student performance. Both studies are positive indicators of the importance of daylight to schools. Though life-cycle cost analysis is not within the focus of the proposed research, the Nicklas and Bailey study provides evidence that cost of added daylighting construction features should not affect design decisions.

2.5. DAYLIGHTING AND BUILDING ENERGY ANALYSIS PROGRAMS

A number of daylighting and building energy analysis software currently exist in the industry and a broad range of simulation software applications has become available for different building performance assessments over the last three decades (Augenbroe 2002).

2.5.1. Daylighting Energy Analysis Programs

The Windows and Daylighting Program instituted at the Building Technologies

Department, Lawrence Berkeley National Laboratory (LBNL 1994), California, has developed a number of computer programs for daylighting energy analyses.

ADELINE is an integrated lighting design computer package developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 12. It contains the lighting tools SUPERLITE and RADIANCE (Fraunhofer-Institut für Bauphysik 2002). RADIANCE is a suite of programs for the analysis and visualization of lighting in design (LBNL 1997). The user input specifies the geometry, materials, luminaires, time, date and sky for the specific analysis space. Data and graphic output includes illuminance and luminance values, with human sensitivity and false color comparisons. RADIANCE is better than other programs because there are no limitations on the geometry or the materials (LBNL 1997). Desktop Radiance is a plug-in module that works with other popular computer aided design (CAD) tools to provide the user interaction and 3-d modeling capabilities. Desktop Radiance combines the *Radiance Synthetic Imaging* with *AutoCAD* capabilities to allow more flexibility to the designer. SUPERLITE 2.0 is a DOS-based program that runs on IBM-compatible personal computers, and is a powerful lighting analysis program designed to accurately predict interior illuminance in complex building spaces due to daylight and electric lighting systems (LBNL 1994).

DAYSIM (Dynamic daylight simulations) and SkyVision are two new computer programs developed by the National Research Council in Canada (NRC 2003 a and b). According to the research team at NRC, DAYSIM is daylighting analysis software that calculates the annual daylight availability in arbitrary buildings as well as the lighting energy use of automated lighting controls (occupancy sensors, photocells) compared to standard on/off switches (NRC 2003 b). SkyVision is a specialized tool for daylighting calculations using skylights and overall lighting energy analysis (NRC 2003 a).

Lumen Micro 2000, developed by Lighting Technologies, Inc. (LTI 2002), is another tool for simulating indoor and outdoor lighting designs, and incorporates CAD capabilities similar to Desktop Radiance. Lightscape is one of the newer lighting programs, developed by Autodesk (Autodesk 2004) that functions with 3D Studio VIZ, Autodesk Architectural Desktop, and any other CAD software to generate highly accurate and convincing renderings.

A number of lighting simulation analyses programs are currently used by architects and lighting designers, other than the important few being mentioned above. Research by Bryan and Autif (2002) compared 4 simulation programs, namely, Lightscape 3.2, Desktop Radiance 3.02, Lumen Micro 2000, and FormZ RadioZity 3.80 to study their individual modeling capacities. Desktop Radiance was found to be the most accurate for lighting calculations but was termed non-user-friendly, and Lightscape performed the best rendering of interior spaces but was inaccurate in sky modeling. Lumen Micro and RadioZity were not considered good lighting programs due to their inaccuracies in building complex room geometries (Bryan and Autif. 2002).

Though a lot of daylighting software is available in the industry, most of these can be used only to conduct daylighting simulations, and do not include building energy analysis. The proposed research will use the DOE-2.1e (version 119) energy simulation software developed by the Lawrence Berkeley Laboratory, which incorporates a daylighting calculation tool (Winkelmann and Selkowitz 1985) along with the building energy analysis program. The software will be used to model different daylighting alternatives of skylights and clerestories, and to study their effect on interior illuminance and total building energy consumption. The daylighting tool allows the user to perform accurate daylighting calculations for a building for every daylit hour of the day, for the entire year (or as might be defined by the user input).

2.5.2. Building Energy Simulation Programs

There are a number of energy simulation software packages available, of which some are public domains, and others have been developed as proprietary software. This section provides a broad survey of the software packages and then a more detailed description of the DOE-2 program.

Two of the most popular building energy software are DOE-2 and BLAST, funded by the U.S. Department of Energy (USDOE), the United States Post office, and the U.S. Department of Defense. These two software have undergone numerous additions and improvements over the past 20 years. The simulation research group at Lawrence Berkeley Laboratory developed the DOE-2 simulation program (LBL 1980, LBL 1993, LBNL 2002). The BLAST (Building Loads Analysis and System Thermodynamics) system is a set of computer programs for predicting heating and cooling energy consumption in buildings, and analyzing energy costs (BSL 2001). Along with DOE-2 and BLAST, Lawrence Berkeley Laboratory has also developed other programs like SPARK (Simulation Problem Analysis and Research Kernel), GenOpt

(Generic Optimization program), BDA (Building Design Advisor), and PowerDOE (BSL 2001). The latest program developed by LBL (along with a team of other research institutes) is called EnergyPlus, which combines the capabilities of the DOE-2 and BLAST programs. Energy Plus is a stand-alone simulation program without a 'user friendly' graphical interface. EnergyPlus reads input and writes output as text files (BTS 2001). There are many software development companies currently involved in creating front-end user interfaces for the EnergyPlus program.

Many other building energy analysis programs are currently in use. ECOTECT, developed by Square One Research Pvt. Ltd. is an environmental design tool which couples an intuitive 3D modelling interface with extensive solar, thermal, lighting, acoustic and cost analysis functions (Marsh 2003). Along with a superior user interface, this program is ideal for pre-design and design phases for solar shading and lighting analysis. ENERGY-10, developed by the National Renewable Energy Lab (NREL 1998) and ENER-WIN, developed by Larry Degelman at Texas A&M University (Degelman 1994), are two other total building analysis programs used in the industry for building energy simulations. The proposed research will use the DOE-2.1e (version 119) building energy analysis program to perform cooling, heating, lighting, total electricity and natural gas use simulations for the school building under analysis. The advantage of programs like DOE-2 is that the user has a clear understanding of what the inputs are and can predict what kind of result are to be expected. Adequate experience with this program allows the user to investigate various parameters that might affect the end result. The drawback of the front-end computer programs is that the user cannot know what parameters are being applied in the background code and what kind of defaults are being applied in the simulations.

2.5.2.1. The DOE-2 Simulation Program

DOE-2 has one subprogram for translation of input (BDL Processor), and four simulation subprograms (LOADS, SYSTEMS, PLANT and ECONOMICS). Each of these subprograms produces reports of the results of its calculations (LBNL 1997). It is capable of handling complex geometries. The input of a detailed zoned building description with the respective weather file and system specifications can generate extensive output reports on all the building performance characteristics. The most commonly used version is DOE-2.1e (version 119), which has the ability to simulate a thousand zones (LBNL 2002). Figure 2.1 represents the working flow chart of the DOE-2 program.

The DOE-2 program also includes a “daylighting calculation model”. The effect of daylighting on the building cooling, heating, and lighting electricity loads can be calculated using the daylighting model in conjunction with the LOADS and SYSTEMS functions. The daylighting input is required in the LOADS portion of an input file. The Daylighting Simulator in DOE-2 has three main stages: Daylight factor preprocessor, Hourly daylighting simulation, and Hourly lighting control simulation. Daylight factors can be determined at user-specified reference points (Winkelmann and Selkowitz 1985).

The DOE-2 building energy simulation program will be used in this research to determine the effect of daylighting on the energy loads for an elementary school in College Station, TX.

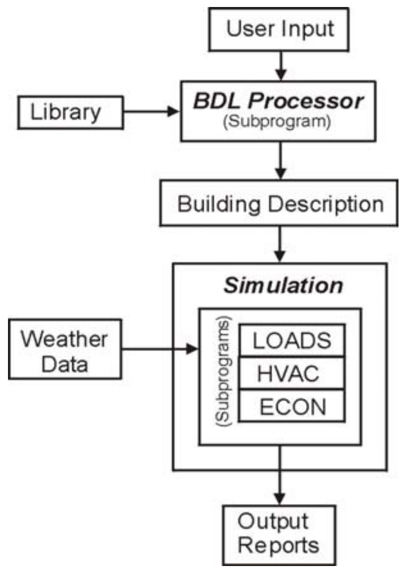


Figure 2.1 -The DOE-2 flowchart (Source: LBL website; http://gundog.lbl.gov/).

2.6. THE USE OF DOE-2 IN BUILDING SIMULATION

"The DOE-2 program provides the building construction and research communities with an up-to-date and unbiased computer program for building energy analysis. Using DOE-2, designers can quickly determine the choice of building parameters, which improve energy efficiency while maintaining thermal comfort" (LBNL 1997). A number of research studies have validated the program and it has been extensively used in the building construction industry.

Gottfried (1996) has given a brief summary of DOE-2 and then reviewed an energy-efficient building retrofit for the City of San Diego Environmental Services Department. A baseline DOE-2 model was created in collaboration with the local utilities and the Electric Power Research Institute (EPRI), incorporating as-built drawings for the building and historic energy consumption figures. This DOE-2 model was then enhanced to meet the California's Title 24 Energy Code, as well as ADA, fire safety, and tenant improvement upgrading. After determining the base case and code compliant models, the possible energy efficient opportunities were discussed depending on energy savings and cost estimates, and a third, more enhanced DOE-2 model was developed. The final model showed an annual energy consumption of 8.4 kWh/sq.ft, which represented a 60 percent decrease from the base case, and 50 percent decrease from the code compliant model. Results indicate that DOE-2 is an effective program for building energy analysis, which can lead to development of energy-effective building solutions that can yield a high economic return. The DOE-2 program will be used in the proposed research for daylighting and building energy analysis.

Pedrini et al. (2002) discussed a DOE-2.1e simulation model developed to analyze building performances in Brazil. The methodology was divided into three areas. The first part involved the building representation input to the simulation software, while the second and third phase involved a walk-through and energy audit of the reference building for calibration and accuracy of simulation. The Eletrosul Building in Brazil was explained as an example. The first DOE-2 model was developed using architectural and mechanical data available for the building. No site visits were involved, and an estimate of the building energy use was generated. The model was then refined using the exact thermal envelope details, and detailed schedules, and the results of simulation came closer to the real values. The information input after the audit and walk-through phase brought the model more closer to the real values, and thus calibration was achieved. The later half of the paper spoke about six other cities in Brazil that had been selected for the implementation of the project. The same methodology was applied to simulate one building from each of these six cities. The software chosen for this task was the VisualDOE, a friendly interface to DOE-2.1E. The schedules description was found to be the most significant stage in model calibration, and utility demand data recorded every 15 min in digital form was a good source of information. Potential to include a set of default values adjusted to typical buildings, and a sensitivity tool embedded in the software was also discussed. The methods applied in this study are similar to the methodology that will be used in the proposed research. Further, the analysis space being a school building, it is anticipated that the schedule descriptions will be a very important part of the DOE-2 model description.

In another study by Akbari et al. (1999), prototypical buildings with reflective and absorptive roofs were simulated using DOE-2 to evaluate the annual savings produced due to roof reflectivity. This study also accounted for the effect of roof insulation and reflectivity on the heating and cooling energy loads. '*Albedo*' is defined as a hemispherical reflectivity integrated over the solar spectrum. High and low albedo roofs were analyzed, and the energy consumption and cost difference was applied to understand their character. An average roof albedo value of 0.25 was estimated from digitized photographs taken over certain cities. Values for Atlanta and Philadelphia were selected as base cases for the south and north. Average gas and electricity prices for the areas were applied to calculate costs of heating and cooling. A total of eleven U.S. metropolitan statistical areas (MSAs) representative of the entire U.S. were considered, and national energy savings were predicted, using the simulated savings data from these 11 regions. The largest savings were observed in the hottest and sunniest cities, and the savings reduced as the climate became cooler (to the North). The predicted energy savings in the simulation study were underestimates as the DOE-2 model applied here underestimated savings; the same simulations if made today, might have led to different results. Results indicate that DOE-2 is an effective energy program to analyze effect of building materials on energy consumption and cost analysis.

Chirarattananon and Taweekun (2003) analyzed required criteria for successful implementation of the Energy Conservation Promotion (ECP) Act of Thailand focusing on the energy effective measures for designated buildings. Four prototypical reference-building models were studied, one for each building type (office, hotel, hospital, and department store). Heat gain through the building envelope was found to be responsible for 30-40 percent of energy use in a building, and retrofits were suggested to counter the same. For air conditioning equipment in commercial buildings, setting the temperature of the supply chilled water to a higher value and that of the condenser water from the cooling tower to a lower value offered energy saving benefits. Overall replacement of existing AC units, with ones with higher EER (Energy Efficiency Ratio) was suggested for government buildings. Replacement of incandescent lamps with compact fluorescent lamps, use of electronic ballasts instead of magnetic ballasts, and a need to utilize more daylight was suggested. Turning off the unnecessary lights during lunchtime saved about 24 percent of electrical energy in office buildings. A 'combined retrofit' involving all these recommendations was suggested to reduce the energy consumption in most buildings. This study indicates the feasibility of use of the DOE-2 program to compare and analyze various energy conservation measures in buildings, and thus is an ideal choice to conduct comparative analysis between various daylighting alternatives in the proposed research.

The study by Carriere et al. (1999) explained the process of validating a DOE-2 model, using monitored data for a large commercial building located on the University of Saskatchewan campus, in Canada. It was an experiment to enhance the design and operation of HVAC systems in commercial buildings through the use of accurate thermal simulation models. Various elements, like windows, occupancy sensors, ventilation, and HVAC system set points were evaluated through use of the DOE-2 models. Using monitored hourly building data and available building information, a base case DOE-2 model was constructed that predicted values that matched very well with the measured data for almost all the seasons. To simulate the effect of use of occupancy sensors, the office occupancy schedule factors were multiplied by 70, 50, and 30 percent. The simulated results showed significant savings, but at a significant capital and maintenance cost. Reduction in the cold deck set-point temperature accounted for modest electrical fan energy savings. Reduced outdoor air ventilation, recirculation of indoor air between the occupied and unoccupied spaces in the school, and a ventilation rate drop from 5.4 ACH (air changes per hour) to 4.88 ACH resulted in significant electrical energy consumption reduction. The last two measures described had an effect on energy consumption without an increase in capital investment. Similar to the study by Chirarattananon and Taweekun (2003), these analyses also explained the versatile nature of the DOE-2 simulation program, and further validated the choice of this program for the proposed research.

"DOE-2 has been widely validated by comparing its results with thermal and energy use measurements on actual buildings. DOE-2 has undergone validation by Los Alamos National Laboratory, LBL and at various US and international institutions to show that that the program is sufficiently accurate in energy prediction". Validation gives users confidence that the DOE-2 results are reliable for building energy analysis (LBNL 1997).

In one of the DOE-2 validation studies, Winkelmann and Meldem (1998) conducted tests on a set of 4 houses near San Diego, CA, to verify and validate the predictions of the DOE-2.1 E program for building energy analysis. In order to study different aspects of the simulation calculations, four different, unoccupied, unconditioned house types were considered. The factor under study was the air temperature in the test houses. The four configurations studied were: unshaded windows, shaded windows, white exterior surfaces, and forced night ventilation. Additional analyses were performed to determine the sensitivity to parameters like cloud-cover, ground surface temperature, and infiltration rate. Low mass and high mass houses were two basic type of houses studied using the Pala local weather data and other necessary inputs. The comparison between DOE-2 and room air and surface temperature measurements for the various configurations was used for validation. Both the house types were unoccupied, had no lights or appliances, and were unconditioned.

This part of the literature review shows that the DOE-2 program has been extensively used in the building industry as a reliable building energy simulation tool. It has been validated and is an efficient tool to be used in the proposed research.

2.6.1. DOE-2 Calibration Methods

A number of studies have been done to define procedures for DOE-2 model calibration. These include calibration using measured building data (Kaplan et al.1990, Diamond and Hunn 1981), annual and monthly data (Haberl and Komor 1990 a), short-term hourly monitored data and monthly utility records (Soebarto 1997), daily and hourly data (Haberl and Komor 1990 b; Haberl and Bou-Saada 1998), and three-dimensional graphical methods (Bronson et al. 1992, Haberl et al. 1992).

The proposed research will involve calibration of the DOE-2 base case model. While electricity use calibration will be done at the daily and hourly level, natural gas use calibration will be done at the daily level.

2.6.2. DOE-2 and Daylighting

Winkelmann and Selkowitz (1985) at Lawrence Berkeley Laboratory incorporated the daylighting tool/model into the DOE-2 building simulation program. This model had the capacity to perform accurate daylighting calculations for a building for every daylit hour of the day, for the entire year (or as might be defined by the user input). This was an important addition to an already widely applicable tool (DOE-2), and widened the scope of energy analysis for the energy designer. DOE-2 has been successfully employed by many researchers for daylighting analysis.

"Because 30 to 50 percent of the energy used in a commercial building is spent illuminating the interior of the building, anything that can reduce the need for electric light will significantly lower the energy requirements of the building" (Robbins 1986).

One of the earlier significant studies to analyze daylighting using DOE-2 was by Gates and Wilcox (1984). The study analyzed the effects of using unilateral, clerestory, and toplighting daylight designs in the three California climates, namely, valley, coastal, and mountain. A five-zoned (4 exterior and 1 interior) generic building module of 30.5 m x 30.5 m (100 ft x 100 ft) was used for analysis. Computer simulations were made using differing glazing areas; 30 to 70 percent exterior glazing area in the unilateral case, 0.6 m to 2.4 m (2 ft to 8 ft) glazing height in the clerestory case, and total skylight areas from 1 to 10 percent of the ceiling area were used in the toplighting case. Analysis revealed that daylighting could produce lighting energy savings in excess of 80 percent, and total building energy savings in excess of 30 percent in all three analyzed climates. Optimum glazing areas were concluded for the clerestory and unilateral designs, and were found to reduce cooling loads as compared to the base case. However, larger glazing areas increased cooling and heating loads both. Cooling loads were not reduced in the skylighting case, but heating loads did not increase as much as in the other two cases. The study concluded that, of the designs studied, skylights produced the greatest lighting energy savings and total building energy savings. This study forms the basis of the proposed research in which skylight and clerestory options are analyzed for their daylighting effectiveness and potential to reduce building energy use. The proposed research differs from this study in the following ways: 1) It will not consider a generic building module (hypothetical case), but instead will analyze an actual school building located in College Station, Texas, and 2) It will use three methods for analysis, including actual space walk-throughs and light measurements, use of physical scale models, and DOE-2 simulations for daylighting and building energy analysis.

Arasteh et al. (1985) used the building energy simulation program DOE-2.1 B and C to analyze different building energy parameters. Beginning with the lighting energy savings from the use of daylighting, the effects of fenestration parameters on cooling loads, total building energy, peak demand, initial and operating costs, and chiller sizing was analyzed. Further, daylighting was compared with electric lighting, and their impacts on the cooling requirements in a typical office-building module were studied. The window and skylight modules were considered, and the overall trend observed was that the lighting energy, as a function of the effective aperture, followed a roughly exponential decrease leading to a saturation of daylight and no further savings in electric lighting energy were observed thereafter. Further observations concluded that in both, the daylit and non-daylit cases, the lighting, cooling, and fan energy were the primary energy consumers, and that the cooling and fan energy rose relative to increase in aperture size. The total energy consumption in the daylit case was observed to drop until the daylight saturation stage, and rose with a curve similar to the non-daylit case after that point. This paper addressed the effect of daylighting on lighting and cooling energy use, both of which will be important analysis parameters in the proposed research.

Rungchareonrat (2003) from Texas A&M University did a study on daylighting applications in residential buildings for her master's thesis. The study focused on energy reduction and solar shading potential of daylighting systems in a Habitat for Humanity house located in Bryan, Texas. A maximum 6-foot overhang, a maximum 6-foot overhang with vertical fin, and a 18-inch combined light- shelf, were the three designs analyzed. The study was performed using a physical scale model for daylight factor analysis and the DOE-2 energy simulation computer program for simulating models of the residence with and without applied daylighting designs. Energy use results were reported in terms of the heating, cooling, and electrical energy uses, as compared to the base case. The daylight factors obtained from the actual space, the physical model, and DOE-2 daylighting simulation results were compared. In conclusion, daylight factors obtained from the physical model appeared to be the most reliable, while the DOE-2 presented the lowest values. The combined light shelf system was found to be the most effective in providing daylighting, due to its contribution to interior illuminance. Drawbacks of this study were that real glazing and interior materials representing actual space reflectance were not used in the physical model. This might have led to some discrepancies in daylight factor evaluation. This study provided an understanding of inaccuracies in DOE-2 daylight factor analysis, which will be further explored in the proposed research. The proposed research will use a methodology similar to this study.

In an example of a ‘practical application’ of daylighting design in buildings, Bazjanac and Winkelmann (1989) analyzed ‘The Pacific Museum of Flight’ in Seattle for its daylighting potential. Due to extensively glazed roof and wall areas, a detailed computer simulation using DOE-2.1C was carried out to analyze the exact glazing choices. The sunspace/ atrium feature in the DOE-2 daylighting program was used to simulate stepped and dimming lighting systems and calculate interior illuminance. Parametric runs for glazing alternatives and automatic lighting systems formed the basis of comparison to develop architectural design parameters. Eight out of the 27 thermal zones in the simulation model were daylit, and 24 were conditioned. Conventional, heat mirror, and low-e glass types were analyzed for their respective performances. Use of daylighting was found to reduce annual lighting consumption by 46 percent in the conventional and heat mirror type application, and 47 percent with low-e glass. Conventional glazing resulted in the highest heating and cooling loads, but the lowest electrical lighting loads. The heat mirror option caused the lowest annual cooling load, and the low-e glazing option caused the lowest annual heating load. A significant lower solar transmissivity of the heat mirror glass, especially in the UV portion of the solar spectrum led to its selection for the wall glazing. Reflective triple glazing was chosen for the roof due to lower simulated total energy levels. A 10-step lighting system was selected as it yielded lower electric consumption from lighting and was more efficient as compared to a continuous dimming system. The application of daylighting reduced the annual electric lighting consumption of the building by 386,000 kWh, and the average monthly peak electric demand by 20 percent. The study led to an understanding of the effect of different glazing options on heating and cooling loads, and discussed different light dimming systems that are used in buildings. The DOE-2 program was found to be effective in analyzing daylighting in an existing building. The proposed research will also analyze an existing school building and will focus on devising optimum glazing sizes to maximize daylight benefit and lowering energy use.

Research by Greenup et al. (2001) discussed the capability of current energy simulation programs to examine buildings for both thermal and visual comfort criteria. Two simulation programs, namely, DOE-2.1 and RADIANCE were used to simulate a two-storeyed house in Australia. DOE-2 performed the thermal energy calculations, and RADIANCE was used for the lighting energy calculations. The DOE-2 results were used to optimize the glazing area and type of glass used in the house. It was found that, even with the optimized glazing design, there were certain periods during the year when significant visual discomfort would occur in the spaces. The authors explained the phenomena by means of computer visualizations of the spaces. The pictures indicated the need for more detailed analyses of the lighting calculations from the point of view of visual and thermal comfort. The aspect of glare control will be handled in the proposed research using user-defined target illuminance and glare values in the DOE-2 daylighting input.

2.7. DAYLIGHTING CASE STUDIES

Wayne et al. (1984) used the building energy analysis software BLAST to study effect of roof apertures (roof monitors) on the electric lighting, cooling, and heating energy in a single-storied office-building prototype. The building was assumed a 30.5 m (100 ft) square in plan, with 1.07 m (3.5 ft) high windows running the full length of the walls and a roof daylighting system consisting of double-pane 60 deg. tilted roof monitors. Aperture Ratio was described as ‘ratio of total illumination (roof) glazing area to total building floor area’. Multiple simulations were run for two configurations of monitors: one with south facing, and the other with equally distributed east and west facing monitors. Aperture ratios were varied from 1.25 to 10 percent. For small aperture ratios (0 to 2.5 percent), electric lighting energy consumption went down rapidly with every addition, whereas it went down less rapidly for larger ratios (2.5 to 10 percent). Cooling energy showed reduction with increasing aperture ratios until a certain point, and then increased with high ratios due to solar heat gains, while heating energy consumption showed an opposite relation. Final comparisons between all configurations indicated the potential to reduce both the cooling and heating energy consumption, but savings in lighting energy were much more substantial. Manually operable solar shading devices were suggested to control excess solar gains whenever required. The study analyzes the monitor type of daylighting option for a hypothetical office building and thus differs from the proposed research that analyzes skylight and clerestory options for an existing school building. The proposed research will compare lighting, cooling, and heating loads for daylighting options with varying glazing areas, which is similar to the method used in this study.

Another study by Kim et al. (1985) at Texas A&M University, analyzed classroom and atrium spaces in a university campus building through the use of actual measurements, computer simulation, and physical models. As part of the daylighting analysis for the classroom, actual daylight levels were measured at 20 points inside the spaces, and daylight factors were also calculated using the computer program, MICROLITE. The analysis concluded that the computer generated daylight levels were proportional with actual daylight levels, but were almost twice in value. This difference was mainly attributed to the presence of furniture and other objects in the actual space that absorb light energy. Scale model daylight levels in the atrium were also shown to overestimate by 30 percent. That error was attributed to the high reflectance of scale model materials and absence of furniture in the model space. Analysis of daylighting using scale models will be one of the methods used in the proposed research. This study explains the importance of calibration in scale models, which is an important step in the proposed research.

The research by Treado et al. (1984) studied the individual impact of various fenestration options on space heating, cooling, and lighting loads in a single floor commercial building for the Washington D.C. climate. The NBSLD-2 building energy analysis program, comprising of a fully integrated daylighting model called DALITE was used as the analysis tool. A set of guidelines was proposed enabling the preliminary design decisions to be made regarding location, size, type, and configurations of the fenestration types. A total of thirty-one options were studied for north and south facing windows, skylights, and clerestories. The use of skylights (with a 2 percent optimum size) was found to be the most efficient option to minimize total building energy and maximize daylighting. Skylights were shown to reduce electric energy by 77 percent as compared to non-daylit base case. The heating loads were not significantly affected through daylighting, but the cooling loads decreased. Clerestories were found to be more effective than unilateral glazing, both daylighting and energy reduction.

The study by Zain-Ahmed et al. (2002) discussed the savings achieved through the use of daylight in passive solar design buildings in Malaysia. Interior illuminance was estimated on normal working planes in simple building configurations through the use of simulated exterior illuminance levels. Illumination on these planes decreased the need for artificial lighting, leading to a reduction in building energy consumption. A simplified analysis tool called NORMA was used to calculate the overall cooling load on the buildings. The cooling load of a simple building with glazing areas between 10 percent and 100 percent WFR (window to floor area ratio) were simulated, and the heat gains through these openings were calculated. The results indicated that at least 10 percent savings could be produced through the use of simple daylighting strategies alone, and these savings could increase through an integrated design of daylighting and shading devices.

Researchers have used different computer programs to study daylighting in buildings. Two daylighting computer models of an existing atrium building created with the ADELINE lighting simulation software were validated by Galasiu and Atif (2002) against measured data collected in the real building with real occupancy. The objective was to determine the accuracy of the software program as a daylighting tool. The computer program ENERGY was used by Shaviv (1998) for pre-design analysis of the building housing offices for the Weizmann Institute's Environmental Science and Energy Research Department, Israel.

Another important study by Bodart and De Herde (2002) evaluated the impact of lighting energy savings in office buildings. The analysis is purely simulation-based through the use of the thermal simulation software TRNSYS, and the program Superlink, belonging to the daylighting simulation tool ADELINE. The modeled office building (proposed) was located in Belgium, and nine window configurations were tested for four different room widths. The influence of the following parameters on the artificial lighting energy consumption was analyzed: glazing transmission factor, window position on the wall and area, window orientation, room width, wall reflection coefficient, and the lighting management systems employed. The potential of energy savings through daylighting integration was found to be high (around 40 percent) for glazing types usually used in Belgian office buildings.

"Skylight shape and fenestration glazing type and surface area are major design parameters to solve the trade-off between daylighting and solar heat gains and to achieve high atrium amenities and significant energy savings" (Laouadi et al. 2003).

Laouadi et al. (2003) described a methodology for development of skylight design tools in atrium energy performance analyses through the application of computer simulation. Three generic atrium shapes and three skylight types were selected as design alternatives for purpose of analysis. ESP-r software was used to compare simulation outputs for the designs with a base case atrium located in Ottawa, Canada. Different fenestration types, glass surface areas, mechanical systems, and lighting control strategies that could be used as criteria for energy-efficiency were also defined as part of the methodology. The proposed research will also use a similar methodology to determine the optimum skylight size for classroom spaces.

2.8. SUMMARY OF LITERATURE REVIEW

This literature review provided an insight into past research in the field of daylighting and building energy simulation. The review was instrumental in understanding the basic concepts of light, daylight, and different daylighting analyses procedures. Due to the year-round daylight availability, College Station region is considered ideal for the application of daylighting principles in school buildings.

There is sufficient evidence that lighting systems and daylighting in particular, have a direct effect on building energy consumption. Presence of windows and daylight also has a positive effect on student performance and behavior. Numerous computer simulation tools are available for building energy simulation and daylighting analysis. Review of different daylighting tools suggested a combined application of two or more analysis methods including actual space measurements, use of physical scale models, and computer simulation techniques for a more reliable approach. These will form the basic methodology for the proposed research.

Review of literature on use of DOE-2 for building energy simulation indicated that it could be an ideal tool for the proposed research. Use of DOE-2 for daylighting analysis was seen to have mixed reviews from previous researchers, and verification of this aspect will be an important part of the proposed daylighting analysis. The literature provided numerous examples of calibrating DOE-2 models to produce accurate and effective suggestions for how to improve building performance through daylighting.

2.9. SIGNIFICANCE OF THE PROPOSED RESEARCH

An analysis of past literature on daylighting indicates that most studies were conducted using computer simulation tools to analyze generic hypothetical space modules for commercial spaces. The proposed research aims at investigating application of daylighting in an existing elementary school building combining three different methods for analysis. Calibrated physical models and computer simulation models are intended to provide the required validity to results. This research is expected to be significant in the following manner:

1) It will provide useful information for the application of daylighting in elementary school buildings in a hot and humid climate, and will be generic to similar school buildings located in similar climates and sharing similar cultures.
2) It will contribute to existing research on accuracy and application of building energy and daylighting analysis using the DOE-2 program and formulate guidelines for efficiency of daylighting techniques.
3) It will develop optimum designs of skylights and clerestories for future applications in elementary school design, and aims at being a guide for the Independent School District administrations.

CHAPTER III

METHODOLOGY

This chapter explains the methodology applied in this research. The purpose of this research was to evaluate the importance of daylighting application in elementary schools in climates similar to that of College Station, Texas. For this purpose, the methodology consisted of the following steps: 1) Selecting an elementary school in College Station, Texas, as a base-case study model, 2) Evaluating actual spaces in the school building to understand daylighting potential through walk-through and daylight measurements, 3) Building a physical scale model of the school building for daylight factor analysis with and without daylighting alternatives, and daylight penetration studies, 4) Developing a computer simulation model of the school building using DOE-2 to compare the base-case situation with a similar daylit case, 5) Comparing the results of the actual space values, physical model measurements, and computer model to constitute results of daylighting application, and 6) Using the DOE-2 output to evaluate the energy consumption of the base-case and similar cases with proposed daylighting designs. A flow-chart representation of the methodology is presented in Figures 3.1-3.3. The methodology is further explained in detail in the following sections of this chapter.

3.1. OVERVIEW OF STEPS

The school under consideration is one of the five elementary schools under the

College Station Independent School District (CSISD) administration. The hourly electricity consumption and monthly natural gas consumption data were obtained from the Energy Systems Laboratory at the Texas A&M University campus. As-built mechanical drawings were also obtained from the lab. These drawings helped in determining the HVAC systems used in the case study building and the data formed a major part of the computer simulation input. This information was used as reference data during the research.

The architects for the school building were contacted, and the actual space construction details were obtained from the architect's office after an informal interview. The architect's office had maintained well-documented original drawings and building specifications of the school building. Blue-prints of these architectural design drawings and construction details were provided by the architects, and this formed the basis of development for the DOE-2 case-study input file. The architectural drawings were further verified with the actual spaces for as-built consideration through a series of visits to the school.

Permission to conduct research in the CSISD was obtained from the 'Research Review Committee' of the CSISD administration. This permission included visits to the school for the purpose of walk-throughs to verify building drawings, and to conduct daylight measurements inside the case-study spaces for daylight factor analysis. The visits were arranged through an interview with the Principal of the school. A representative of the school building administration was to remain present during every visit to supervise the experiments. This study would have remained incomplete without the Research Review Committee's approval, as the visits to the case study site constitute a very important part of this research.

3.1.1. Case Study Site Description in DOE-2

Figures 3.1.Ato 3.1.C represent the methodology followed. The basic building data was used to write the building description and systems information for the LOADS and SYSTEMS inputs in the DOE-2 input file. This led to an uncalibrated DOE-2 base-case simulation model. Hourly data for whole building electric, heating, and cooling consumption for the case-study building was also obtained from the Energy Systems Lab (ESL 2001). This data was used to refine the input file. The base-case model was adjusted to include the measured hourly data and exact lighting and occupancy schedules for a period of tine that permitted isolation of lighting loads. The schedules were found to be a very important part in the overall model calibration process. Two other input parameters specific to the building description, namely FLOOR-WEIGHT and U-EFF were also introduced to calibrate the model. A final base-case simulation model was produced by adjusting certain input parameters and then comparing DOE-2 outputs with the actual data.

3.1.2. Use of a Physical Scale Model

A physical scale model was constructed to understand the daylight penetration inside the classrooms and to calculate the daylight factors inside the spaces. The model was constructed to a scale of 1foot = 1 inch.

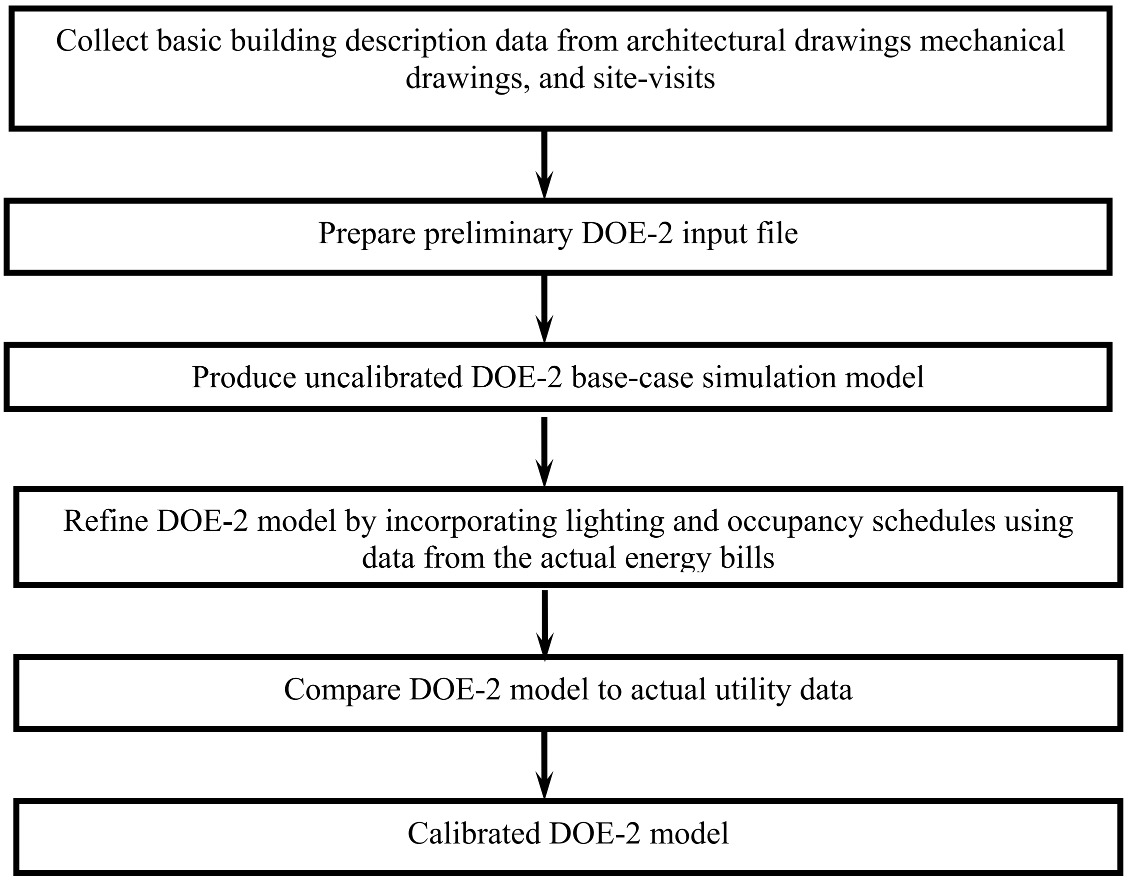


Figure 3.1 - Steps in producing a calibrated DOE-2 model

3.1.3. Daylighting and DOE-2 Energy Simulation

Simulations were run using the calibrated DOE-2 input file and the Houston TMY2 weather file. The initial simulation did not consider daylighting (no daylighting commands were added; DAYLIGHTING=NO). The base case model was then modified to include daylighting and was simulated again to determine the effect of the daylighting input (DAYLIGHTING=YES) in DOE-2. After this comparison, the daylighting model was modified to include the top-lighting alternatives. The daylight factors from the base-

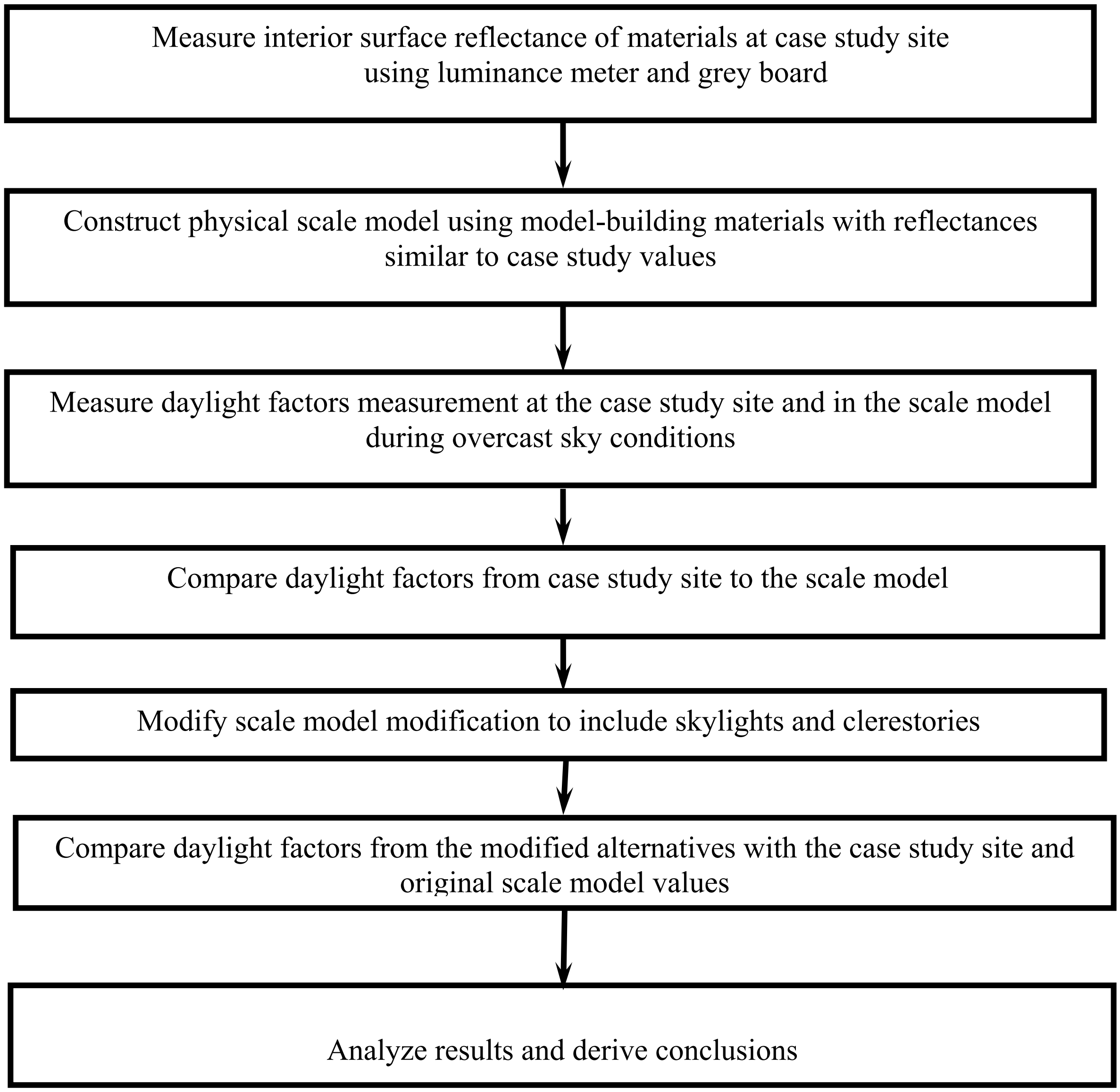


Figure 3.2 - Calibration of physical model and testing of alternatives

case daylighting model were then compared with the corresponding values obtained from the modifications. The energy consumption for total building energy, lighting, cooling, and heating was also studied simultaneously for all the models. This led to determination of the effect of daylighting on the energy usage of the building.

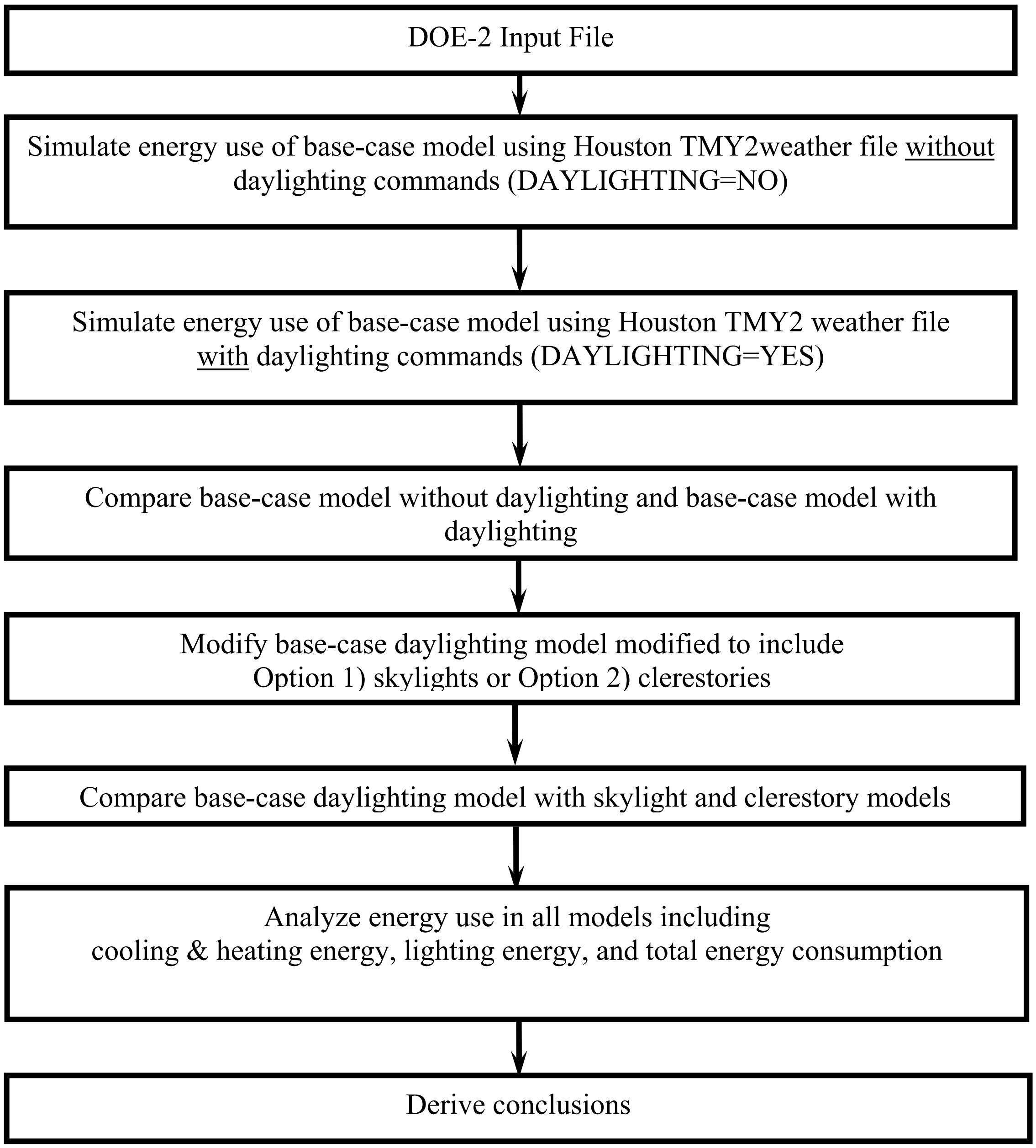


Figure 3.3 - Daylighting and DOE-2 energy simulation

3.2. CASE STUDY BUILDING DESCRIPTION

3.2.1. General Building Description and Space Details

The school building has a total built-up area of 69,000 square feet. The school employs a 2x6 stud wall construction, with 3” face brickwork, 1” air layer, and two 3/4” gypsum board partitions with a 5/8” rigid insulation on light weight concrete on galvanized steel deck in between. The roofing is built-up type with 3/4” rigid insulation and 31/2” batt insulation above the acoustical lay-in ceiling tiles. The floor is a lightweight 4” concrete slab construction with linoleum tile in the circulation and miscellaneous spaces and carpeting in the classrooms and offices. The entire building is single storied and the front faces northeast.

3.2.2. Description of the Case Study Spaces for Experiment

The main purpose of this study was to determine the effect of daylighting on the interior daylight levels and its effect on the total building energy consumption. The classrooms (teaching and learning areas) form the core of a school, and so the daylight experiments were concentrated on classrooms shown in the right half of the school plan. This section of the school consisted mainly of the first to fourth grade classroom areas, and the central library space. This building is at 45 degree tilt to the north-south axis, but for ease of nomenclature, the main entrance side of the school has been termed as the north side, and the other sides have been named accordingly. The titles for the elevations in Figure 3.5 follow this rule. Almost all the classrooms in the section of the school selected for this study were similar in respect of their areas, window placements, and volume. To study similar spaces would have yielded similar results, and it was felt that the study should further restrict to the daylighting analysis of certain groups of typical classrooms on all three sides of the school building. The spaces selected for study were:

a) 2 first grade classrooms on the north side (700 sq. ft each, named as Space 1-1)

b) 2 second grade classrooms on the north side (700 sq. ft each, named as Space 1-2),

c) 2 third grade classrooms on the south side (700 sq. ft each, named as Space 1-7),

d) 2 fourth grade classrooms on the south side (700 sq. ft each, named as Space 1-8),

e) 2 special teaching classrooms on the west side (700 sq. ft each, named as Space 1-5),

f) The central library (3485 sq ft, named as Space 1-4)

The space names shown above denote the user-defined names given to these spaces for computer simulation in DOE-2.

The total area of the school under analysis was 10485 sq. ft. This area is approximately 15% of the total school building area, but includes all the typical classroom spaces facing north, south, and west. Interior photographs of the case study spaces were not permitted by the CSISD Research Review Committee, and hence are not presented in this report.

A plan of the school is presented in Figure 3.4, and the north, south, east, and west elevations are presented in Figure 3.5. The classroom and library spaces selected for this study have been indicated in Figure 3.4 with crossing lines. Table 3.1 presents the floor areas of all spaces in the school building.

Table 3.1 – Floor area per space in the case study building

I.	**CLASSROOMS**		
	SPACE/FUNCTION	SUB TOTAL	**TOTAL**
		(sq.ft.)	
A.	Pre-Kindergarten	1,800	
	Includes 2 classrooms,		
	2 toilets, and storage		
B.	Kindergarten	2,700	
	Includes 3 classrooms,		
	3 toilets, and storage		
	Teacher's Restroom	30	
C.	First Grade	5,470	
	7 classrooms, 7 toilets, storage		
	Teacher's Restroom	30	
D.	2ND, 3RD and 4TH Grade		
	21 classrooms	15,750	
	3 storage rooms	240	
	3 boys rest-rooms	420	
	3 girls rest-rooms	420	
	3 teachers rest-rooms	90	**26,950**
II.	**SPECIAL ROOMS**		
A.	Computer Classroom	900	
B.	Art Classroom and storage	980	
C.	Remedial Reading	750	
D.	Science Classroom	850	
E.	Music Classroom	1,000	
F.	Speech Therapy	150	
G.	Time Out room	250	
H.	Special Education		
	1 classroom	750	
	4 small rooms	1,500	**7,130**
III.	**LIBRARY**		
A.	Stacks and reading area	2,600	
B.	Story time area	225	
C.	Librarian	260	
D.	Storage	400	**3,485**

Table 3.1 – Continued

IV.	**PHYSICAL EDUCATION**		
A.	Gymnasium	6,000	
B.	Coaches Office	150	
C.	Storage	420	**6,570**
V.	**CAFETARIUM**		
A.	Dining space	3,000	
B.	Kitchen and serving	2,000	
C.	Stage	600	
D.	Storage	314	**5,914**
VI.	**CLINIC**	350	**350**
VII.	**ADMINISTRATION**		
A.	Principal	200	
B.	Reception and Secretary	300	
C.	Asst. Principal	160	
D.	Counselor	260	
E.	Conference Room	180	
F.	Restrooms	60	
G.	Faculty Workroom + lounge	920	
H.	Storage	160	**2,240**
VIII.	**ANCILLARY FACILITIES**		
	Student and adult restrooms,	1,340	
	Custodian, and Bookroom		**1,340**
IX.	**MECH./CIRCULATION/**		**15,114**
	EXT.WALLS, COVERED		
	PASSAGES		
X.	**TOTAL AREA**		**69,093**

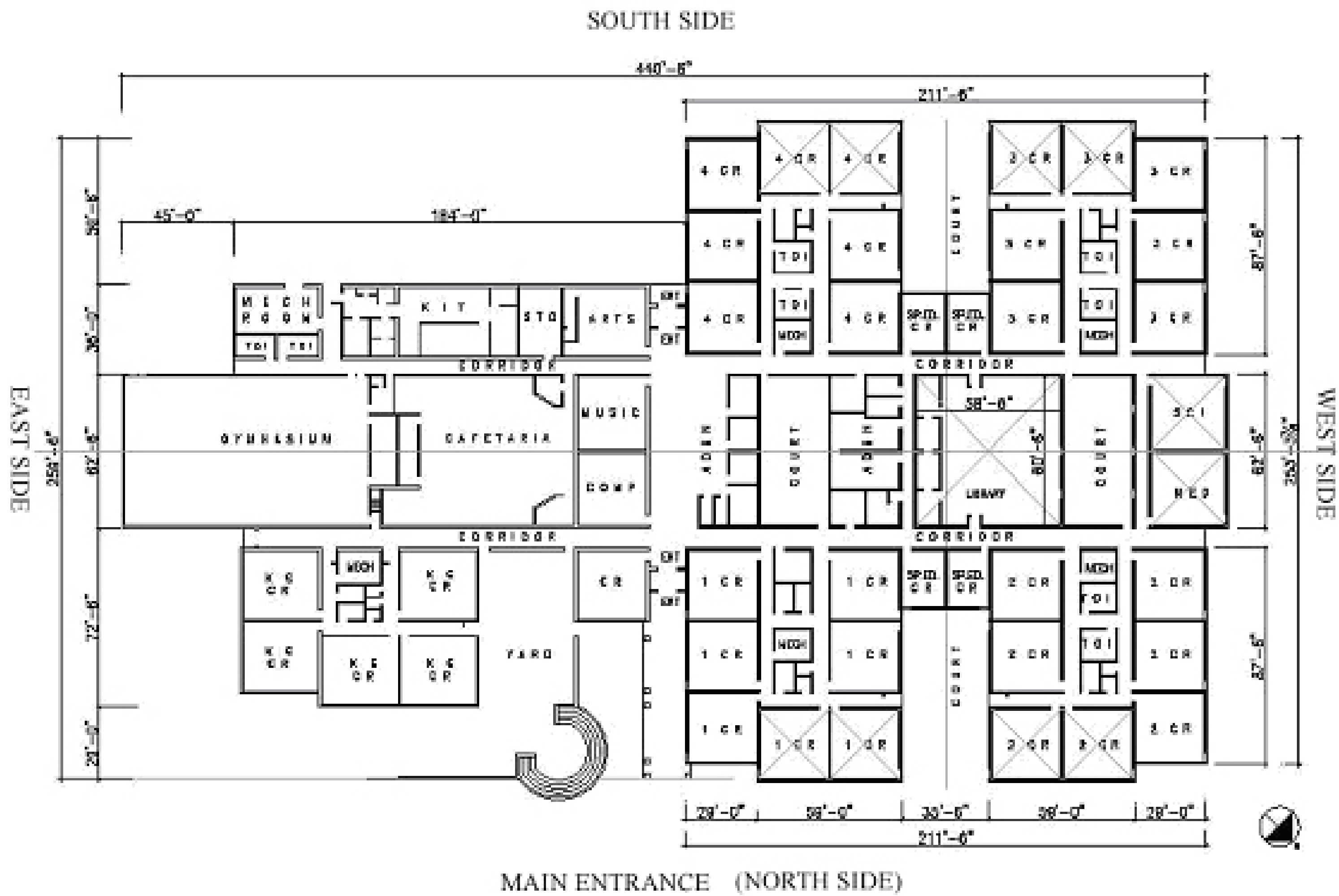


Figure 3.4 – Floor plan of case study school

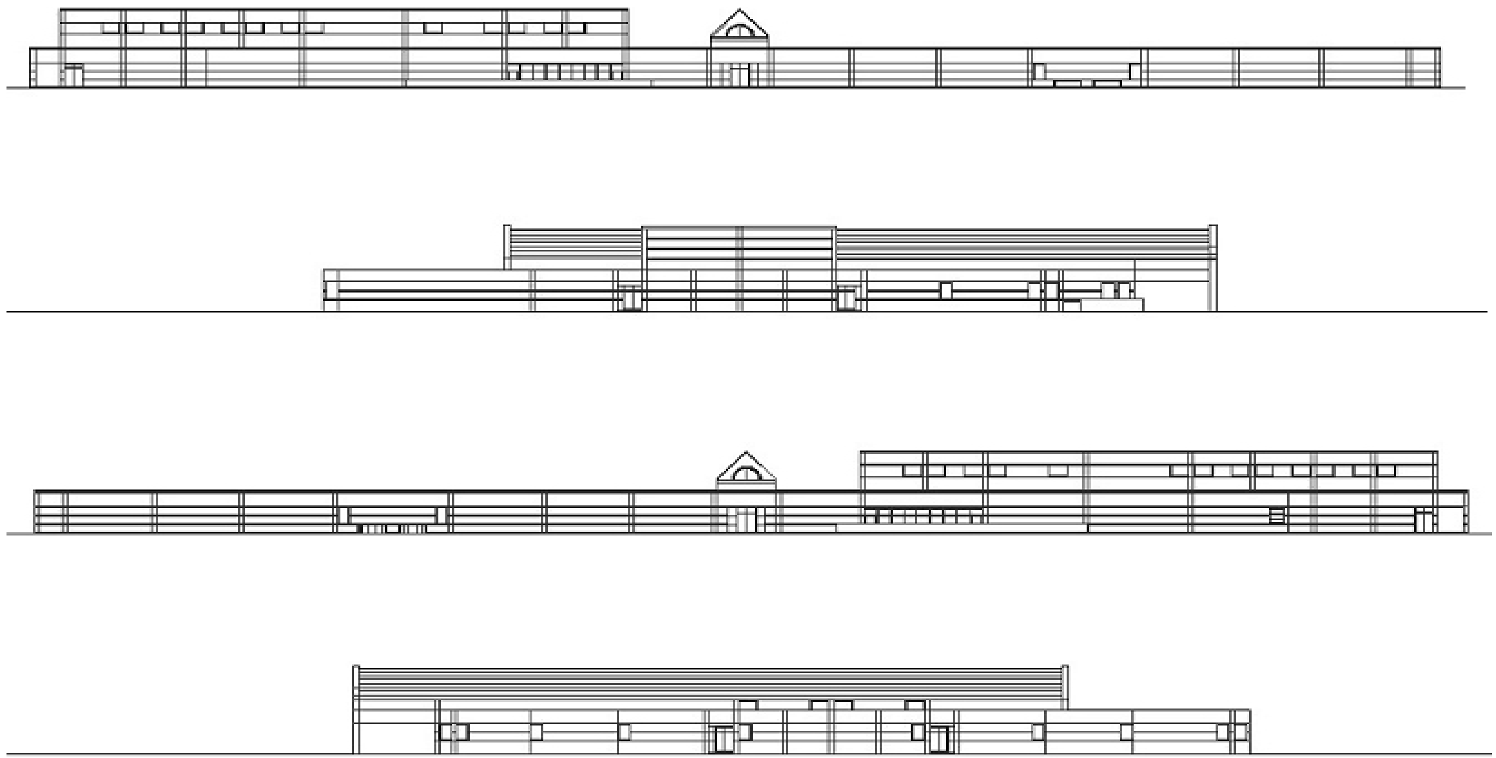


Figure 3.5 –Elevations of the school building (from left-right: north elevation, east elevation, south elevation, and west elevation).

3.2.3. Review of Common Daylighting Designs

A review of the common daylighting designs provides context for overall architectural design understanding and scope. Figure 3.6 presents the typical daylighting sections most commonly used in conventional architecture. These illustrations have been obtained from the IESNA Lighting Handbook Reference Volume (IESNA 1984).

3.2.3.1. Unilateral Design

The unilateral daylighting design is characterized by a continuous line of window glazing on one side of the room. The glazing is generally located close to the roof/ceiling line. The unilateral design is the most commonly found design in residential and commercial buildings. Unilateral designs can be applied for the whole building facade in the form of curtain wall glazing.

3.2.3.2. Bilateral Design

The bilateral daylighting design is used in buildings that can afford to have opposing walls opening to the outdoors for daylight. The room width can be much greater than in the unilateral case, as light can be admitted from both sides of the space. The second window glazing is generally smaller, and located in the upper portion of the wall. This design is common in institutional buildings.

3.2.3.3. Roof Monitor Design

The roof monitor is a part of the roof that is set higher than the surrounding roof area, and has window openings on any one or all four sides to admit daylight. The roof areas on the low bays are generally treated to serve as daylight reflectors. This design is common in single storied residential and institutional buildings.

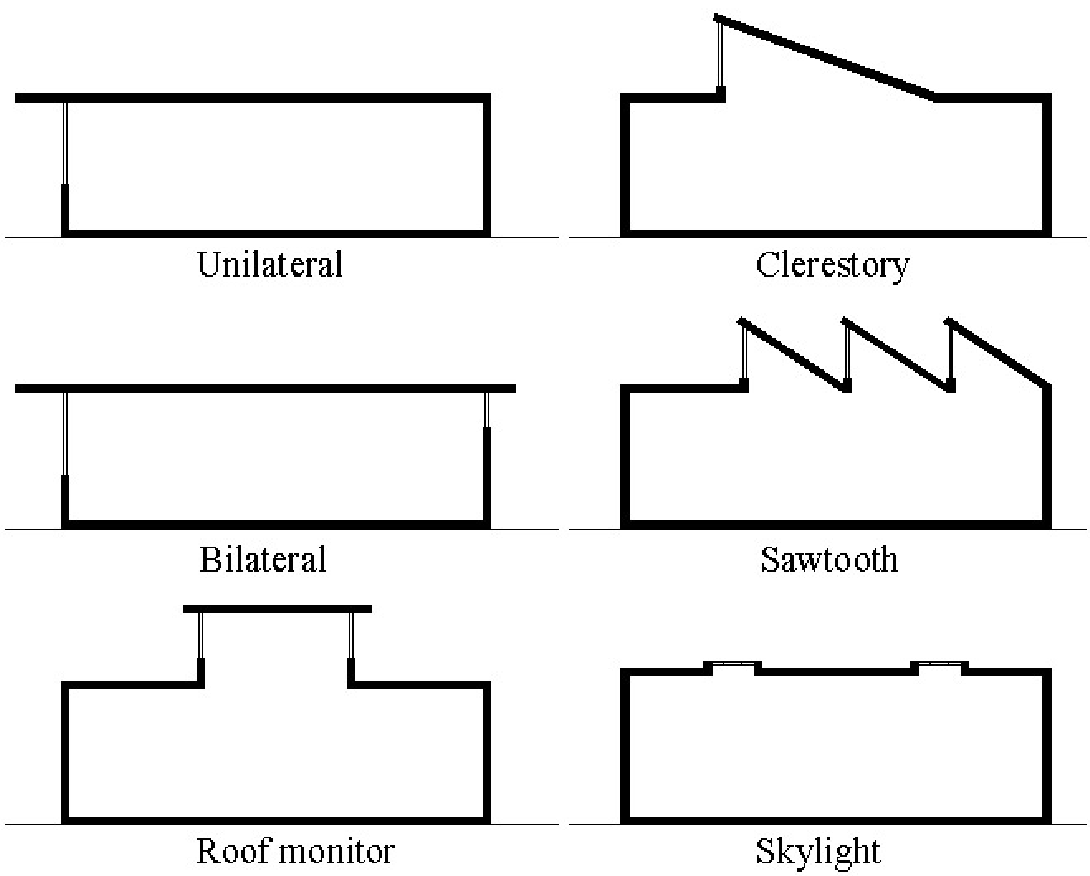


Figure 3.6 –Typical daylighting design sections used in buildings

3.2.3.4. Clerestory Design

A clerestory is that part of a building rising clear of the roofs or other parts and whose walls contain windows for lighting the interior. The additional fenestration on the roof facing in the same direction as the main window aids in overcoming the room width limitations of the unilateral section (IES Lighting Handbook 1984). The clerestory design is generally designed to admit north light into the space due to problems of heat gain and glare. A clerestory normally runs throughout the length of the space that it serves. This design is common to single-storied institutional and commercial buildings.

3.2.3.5. Saw-tooth Design

This design is a variation of the clerestory type. The clerestory windows are arranged in rows to form a saw-toothed design. This fenestration is used principally in low roof, large area industrial buildings. The windows usually face north in northern latitudes; brightness controls are not then required (IES Lighting Handbook 1984).

3.2.3.6. Skylight Design

The skylight design is used in different forms in all types of buildings. The main kinds are the domed, flat paneled and pyramidal skylights. Glazing materials for skylights vary from glass and acrylic panels to glass-fiber reinforced plastics and specially designed skylights with semi-transparent and translucent fabrics. Heat and glare control are the two main problems associated with skylights. Skylight design should be carefully designed to provide for effective seals against moisture penetration and possible dripping from condensation. They also may be used to provide heat control and ventilation (IES Lighting Handbook 1984). The skylight section presented in Figure 3.6 shows the flat paneled skylight, and the same can be substituted with a domed or pyramidal skylight for design variations.

This research focuses on the effect of the two top-daylighting options, namely, the clerestories and skylights, on energy consumption and daylighting quality in the case study elementary school in College Station, Texas.

3.2.4. Proposed Daylighting Options

Skylights and clerestories are proposed as the two daylighting alternatives for this school building and their effects were analyzed for building energy consumption and interior daylighting potential. The details of the proposed designs are presented in Figures 3.7-3.10.

Figures 3.6-3.7 show the single skylights per space in the classrooms and the multiple skylights in the library space. Figure 3.8 shows the single clerestory proposed in the classroom space. Clerestories in all the spaces face north, except the south side classrooms, which have them facing south. Though a separate analysis of south-facing clerestory could have been made, it was not within the scope of this research. Figure 3.9 presents the double clerestory case for the library space. This same section has also been used for the west-facing classrooms, and so the section for those spaces has not been shown again.

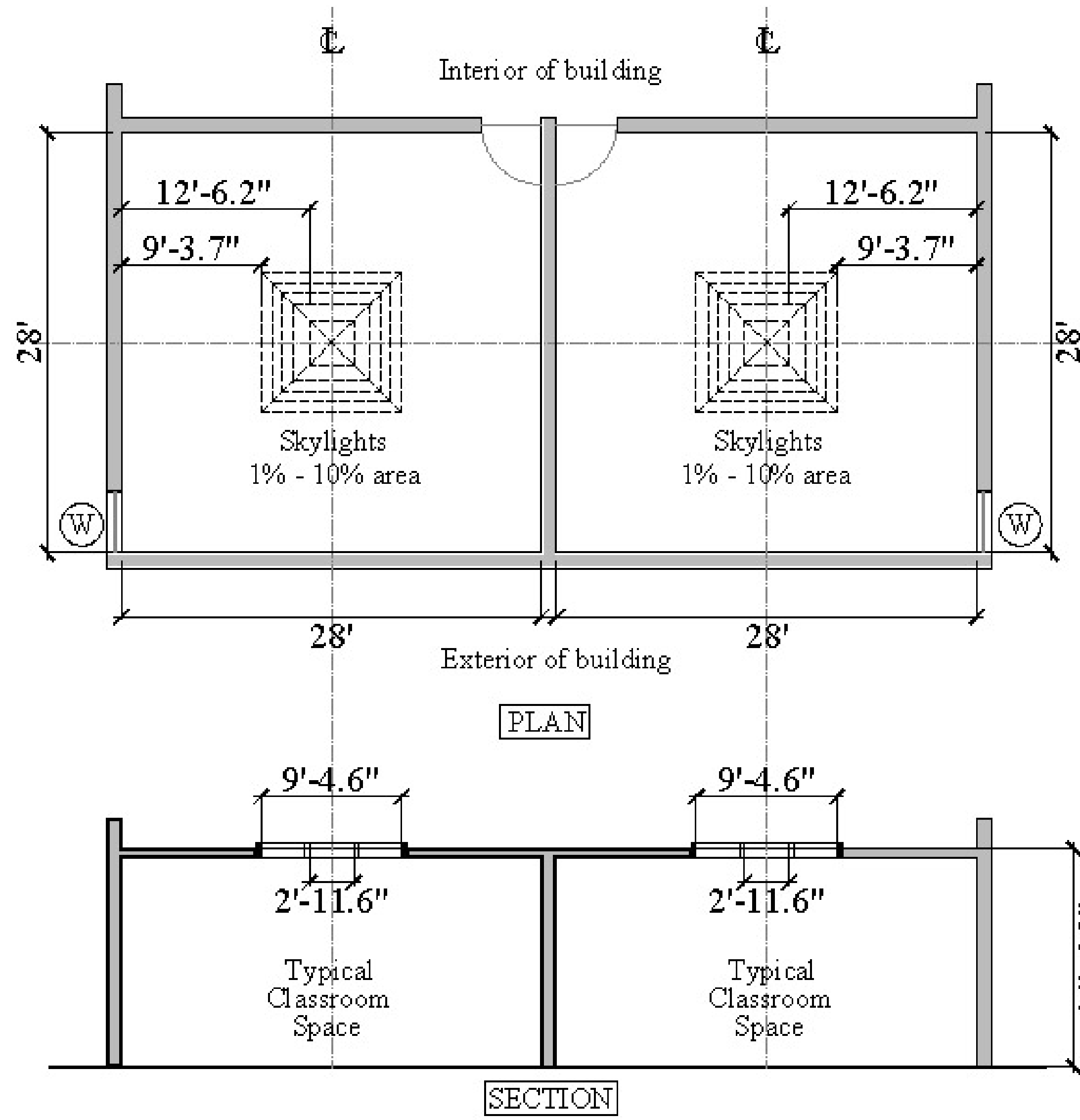


Figure 3.7 –Plan and section of the typical classroom space units. One skylight per space has been proposed for daylighting analysis. The skylight areas vary from 1% to 10% of the roof area, the smallest skylight being square of 2.97' and largest of 9.38'.

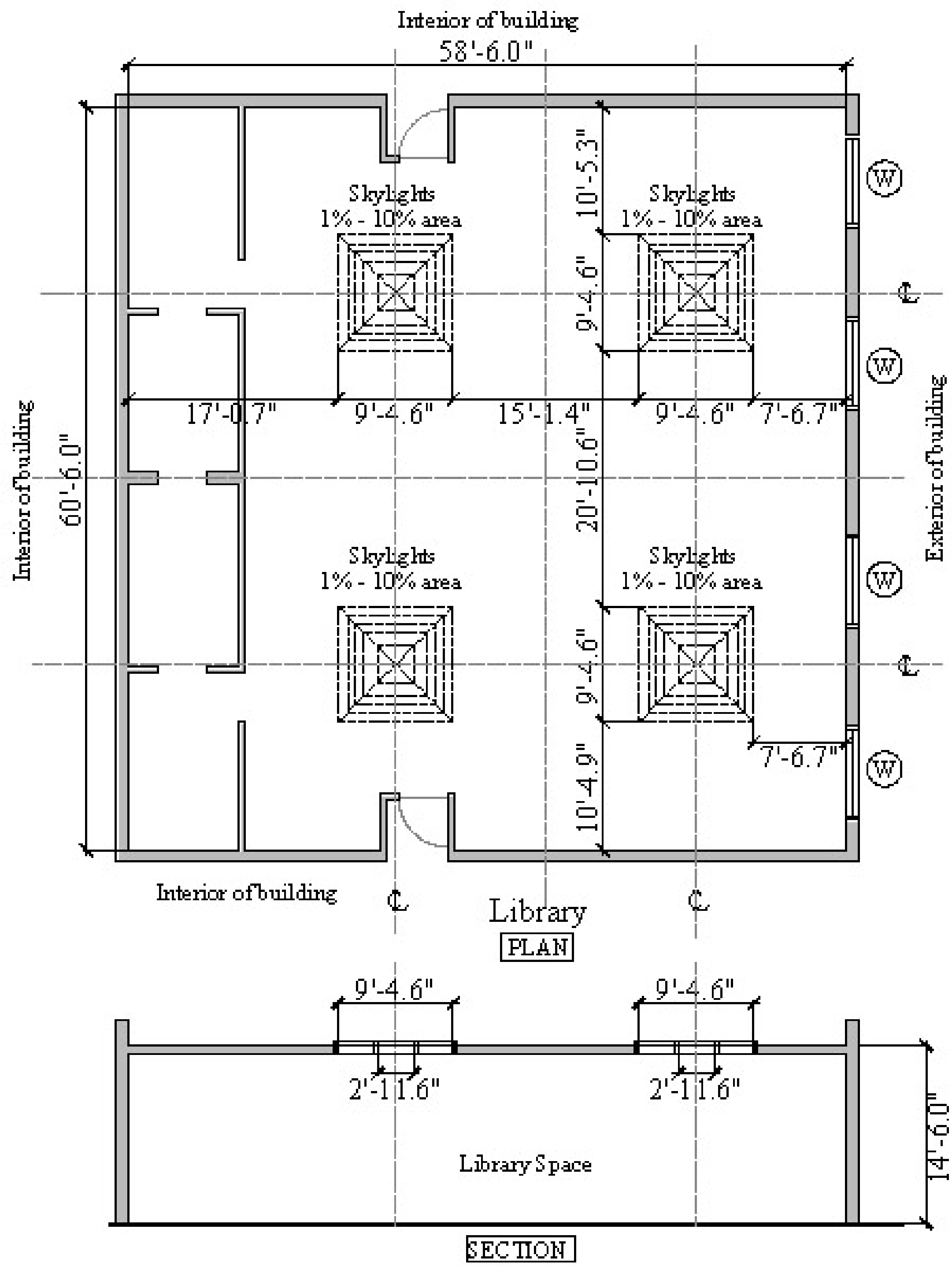


Figure 3.8 –Plan and section of the library space. Four skylights have been proposed for daylighting analysis. The skylight areas vary from 1% to 10% of the roof area, the smallest skylight being square of 2.97' and largest of 9.38'.

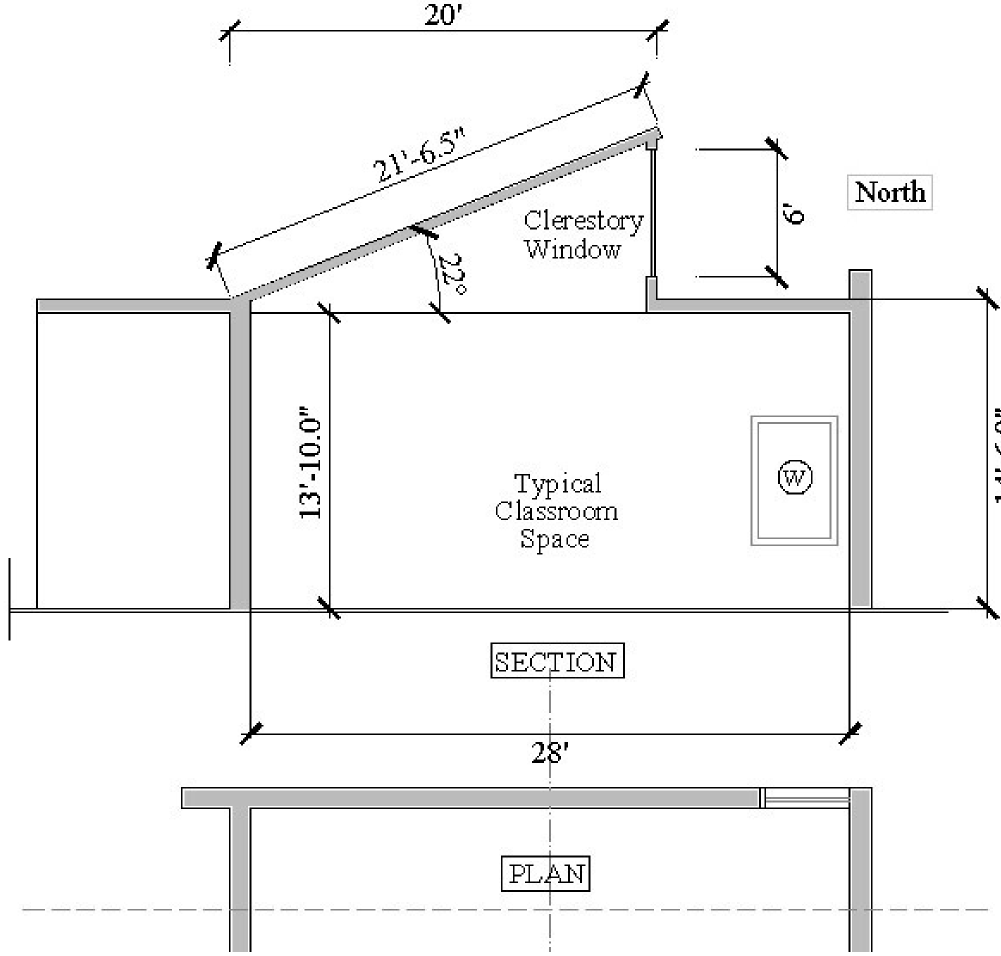


Figure 3.9 –Section of the clerestory window in a typical classroom space. A 6 ft glazing has been shown. This is the largest glazing size proposed. Other glazing heights are from 2 ft-5 ft.

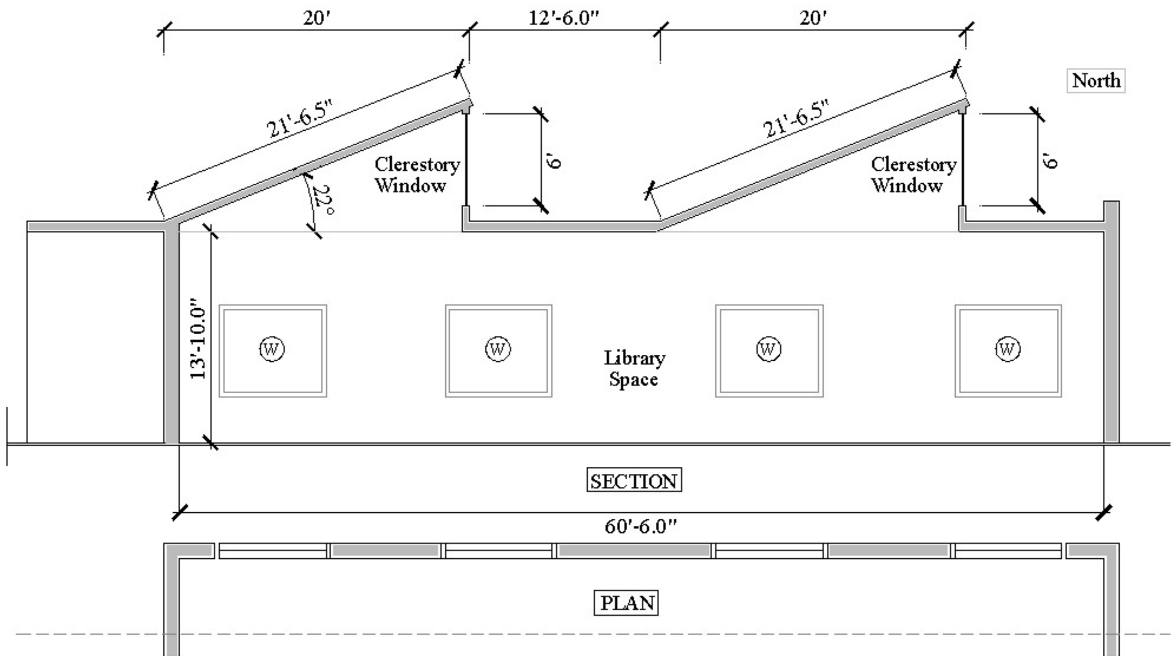


Figure 3.10 –Section of the clerestory windows in the library space. A 6 ft glazing has been shown as in Figure 3.9. The two clerestory windows are arranged facing north.

3.3. MEASUREMENTS ON SITE

Before the physical model could be calibrated, it was necessary to determine interior surface reflectances of the building materials in the analyses spaces at the case study site.. Reflectance of each surface in the space was measured using a luminance meter. A photographic grey board with a known reflectance of 0.18 was used as the standard to derive the reflectance of the desired surface. The formula used was: $\text{Ref.}_{\text{surface}} = \text{Ref.}_{\text{grey board}} \times (\text{Lum}_{\text{surface}} / \text{Lum}_{\text{greyboard}})$. Table 3.2 presents the space reflectances as measured inside the case study building.

Table 3.2 - Space reflectances inside the case-study spaces

Surface	Luminance surface	Luminance grey board	Reflectance grey board	Reflectance-surface (%)
Wall-white painted	49.80	12.84	0.18	72.29
Floor-dark gray carpeted	0.67	1.98	0.18	6.09
Ceiling-white sheets	28.51	-	0.18	
Board-black	0.46	0.8	0.18	10.35
Door-light brown painted	1.93	0.67	0.18	51.85
Table-light brown laminate	3.31	1.53	0.18	38.94

3.4. PHYSICAL MODEL CONSTRUCTION AND CALIBRATION

3.4.1. Physical Model Description

The use of a physical scale model for daylighting analysis was an important component of this research. The daylighting measurements were compared with the real values from the actual space as obtained through the walk-through observations.

The model was built to a scale of 1 inch = 1 foot. Model materials for the internal surfaces were carefully selected to match the reflectance values of the actual materials in the case study spaces. The entire model was built out of a combination of 3 materials to obtain complete opacity. The external layer was a 1/4” thick black foam board, followed by a 1/2” thick white foam board, and the internal surface was a crescent board of color depending on the reflectance value for that surface (for example, a dark gray matted crescent board, color number 924 was used for the floor, which corresponded to the 6% reflectance of the carpeted flooring in the actual space). These model materials were selected due to their flexible nature in order to experiment with different daylight openings. The same flexibility might not have been achieved if the construction material used had been wood. The window openings were treated with 1/8" clear glass pieces to correspond with the glass openings in the actual space. Similar treatment was used for all the top-lighting solutions that were experimented with in the model. The model roof was not fixed, and could be substituted for different combinations of skylights. Adequate openings, other than the windows, were provided in the walls to insert the cables for the illuminance (light) meter, and also for taking internal photographs using a digital camera. These openings were kept completely closed while taking internal daylight measurements. Internal photography helped in a qualitative analysis of the physical model space. The scale model was constructed for two typical classroom units (which are similar throughout the building) and these were rotated to match their respective orientations in the real space. The window details are same for all parts of the school building. Daylight values were measured under overcast sky conditions and the results were compared with the actual space values and the DOE-2 daylighting simulation outputs. Analysis of the daylighting measurements from all three cases is presented in Chapter IV. Figures 3.11-3.12 shows the base case model case, while Figures 3.15-3.21 show the different skylight and clerestory options.

3.4.2. Physical Model Calibration

The materials chosen for the physical model were such that their reflectances were as close as possible to the reflectances of building materials in the actual space.

These were arrived at with the help of the Reflectivity of Materials table. Table 3.3 shows the model reflectance values for the specific materials used in construction.

Daylight factors were measured at the case study site and in the physical scale model during overcast sky conditions, and were compared for model calibration and analysis. After sufficient calibration, the physical model was modified to include top-lighting options including skylights and clerestories, and the daylight factors were measured for these alternatives. The new daylight factors were then compared with the original values and analyzed for their individual potential.

Table 3.3 – Physical model reflectances

Space Surface	Reflectance-surface (%)	Model material	Color number	Reflectance-material (%)
Walls	72	French Gray	962	75
Floor	6	Dark Gray	924	14
Ceiling	-	Buff	3291	25
Board	10	Smooth Black	921	7.5

As can be seen form Figures 3.13 and 3.14, the presence of a single window in the classroom spaces creates a very dark interior, at the same time creating a bright glare area near the window. The wall surfaces, though having a reflectance of 72% are seen as dark gray or black for most part of the space. This was the main problem observed during a walk-through of the case study school building. The photographs in these figures were taken for the opposing windows for the two classroom spaces. The square cutout in the left photograph is the camera-hole, which has been blocked using opaque board.

Figure 3.11- Base case (no roof)

Figure 3.12- Base case in plan (no roof)

Figure 3.13- Base case interior view 1

Figure 3.14- Base case interior view 2

Figure 3.15- Clerestory case (no glazing)

Figure 3.16- Clerestory case 2 ft glazing

Figure 3.17- Clerestory case 4 ft glazing

Figure 3.18- Clerestory case 6 ft glazing

Figure 3.19- Skylight case (10% area)

Figure 3.20- Skylight case (7% area)

Figure 3.21- Skylight case showing cutouts (cutouts were used to change the skylight glazing areas from 1% to 10%. Example of a 7% case is shown in Figure 3.15).

3.4.3. Daylight Measurement Tools

A Konica Minolta Luminance Meter LS-100 was used for luminance measurements. This luminance meter has a range of 0.001 to 299,900 cd/m^2 (units are candelas / sq. meter) with a 1-degree acceptable angle. This light meter is in the form of a hand-held gun, and was used to measure the luminance of internal surfaces and a gray board, in units of candelas/square meter. The device was held at a distance of 6 inches – 1 foot from the respective surface for measurement. Two different illuminance meters (Minolta Illuminance Meter T-10 and Minolta Illuminance Meter T-10M) were used to measure the daylight factors inside the spaces. Both the illuminance meters had a measuring range of 0.01 to 299,900 lux. The T-10M instrument was laid flat at the desk level (in this case 2.5 feet from the floor) with the sensor facing up, and was used to measure the interior illuminance in units of lux. A simultaneous measurement was taken outside the space using the T-10 instrument to measure exterior illuminance at exactly the same time. Daylight factor (%) was determined as the ratio of the 'interior illuminance at a point inside the experimental space due to daylight' with the 'simultaneous exterior illuminance outside the experimental space on a horizontal plane from an unobstructed hemisphere of overcast sky'.

The same method was applied in the case of the physical scale model. The values were then compared, and were a useful tool in the physical scale model calibration.

3.5. BASIC SIMULATION WITH THE DOE-2 PROGRAM

3.5.1. Building Description for the Simulation Program

The case study building was represented in the DOE-2 building simulation program through inputs in the LOADS, SYSTEMS, and PLANT sections of the input file. The data required for input into the LOADS section of the input file was derived from the architectural drawings and specifications obtained from the architect's office in College Station, Texas. The data required for input to the SYSTEMS and PLANT sections was obtained from the monthly utility bills, measured hourly data, and mechanical drawings for the school building, as obtained from the ESL, Texas A&M University. Data that was not available was input using the average values from the DOE-2 reference manuals (LBL 1980, LBL 1993). The basic input details are presented in Tables 3.3 – 3.4. College Station is located on latitude of 30.6 and a longitude of 96.22, and these values were used to specify BUILDING-LOCATION in the input file.

Other details in this input category were an azimuth of 225, time zone 6, and an altitude of 610 above sea level.

Table 3.4 – SPACE-CONDITIONS input details in LOADS section of DOE-2

SPACE-CONDITIONS GENERAL INPUTS		
OFFICE	**INPUT**	
NUMBER-OF-PEOPLE	20	From the actual data
PEOPLE-HEAT-GAIN	400	ASHRAE Standard
LIGHTING-TYPE	Recessed Fluorescent	From the actual data
LIGHT-TO-SPACE	0.8	DOE-2 reference manual
LIGHTING-W/SQFT	1.7	Approximate Value
EQUIPMENT-W/SQFT	1.8	Approximate Value
INF-METHOD	AIR-CHANGE	DOE-2 reference manual
FLOOR-WEIGHT	0	Custom Weighting Factors
ZONE-TYPE	Conditioned	From the actual data
DETAILS DIFFERENT FROM GENERAL		
CLASSROOM	**INPUT**	
NUMBER-OF-PEOPLE	90	From the actual data
GYMNASIUM	**INPUT**	
NUMBER-OF-PEOPLE	50	From the actual data
LIGHTING-TYPE	Incandescent	From the actual data
LIGHT-TO-SPACE	1	DOE-2 reference manual

Table 3.5 – System input details in SYSTEMS section of DOE-2

SYSTEMS DESCRIPTION		
ZONE-CONTROL		
DESIGN-HEAT-T	70	Estimate from the actual data
DESIGN-COOL-T	82	Estimate from the actual data
THROTTLING-RANGE	4	DOE-2 reference manual
THERMOSTAT-TYPE	PROPORTIONAL	DOE-2 reference manual
SYSTEM-CONTROL		
HEAT-SET-T	130	Estimate from the actual data
COOL-SET-T	60	Estimate from the actual data

Table 3.5 –Continued

SYSTEMS TYPES		
NAME	**Zones served**	
VAVS (variable air volume)	SPACES: 1-1 to 1-12	From mechanical drawings
MZS (multizone)	SPACE 1-13	From mechanical drawings

3.5.2. DrawBDL Representation of the Case Study Building

A graphic representation of the base case model is presented in Figure 3.22 using the DrawBDL 3.0 computer program developed by Joe Huang and Associates (2000).

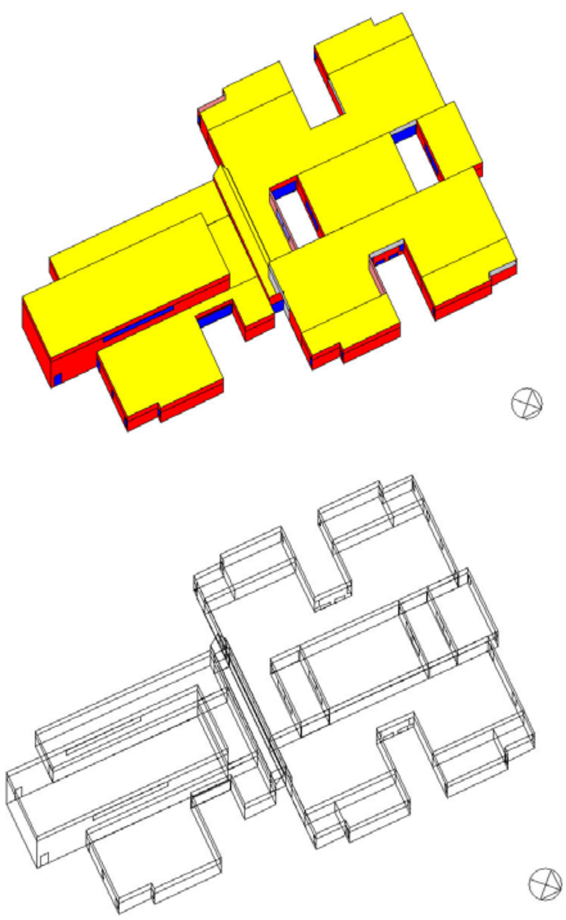


Figure 3.22 – Base case model represented using the DrawBDL program

The base case DOE-2 model was modified to include the daylighting commands and daylighting strategies of skylights and clerestories were introduced to analyze their effects. Figures 3.23-3.33 represent the proposed daylighting options in the DrawBDL base case model.

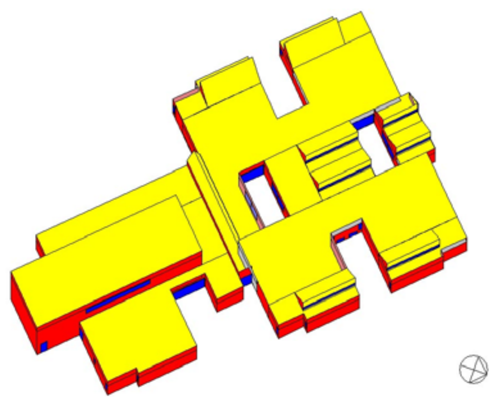


Figure 3.23- Clerestory 2 ft glazing case

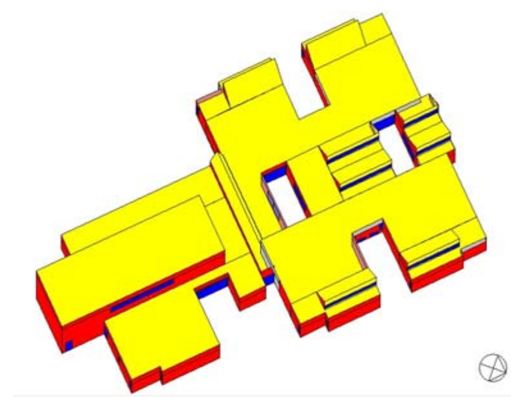


Figure 3.24- Clerestory 3 ft glazing case

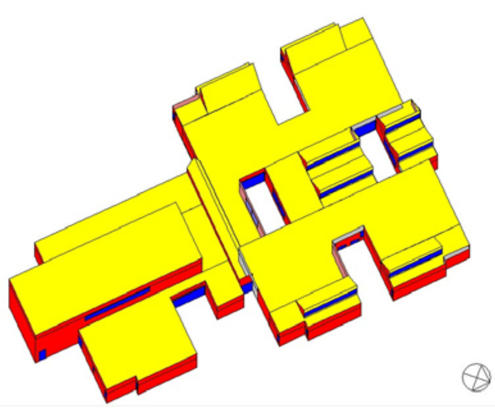


Figure 3.25- Clerestory 4 ft glazing case

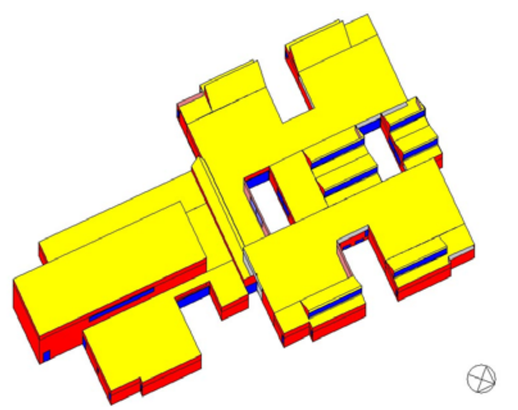


Figure 3.26- Clerestory 5 ft glazing case

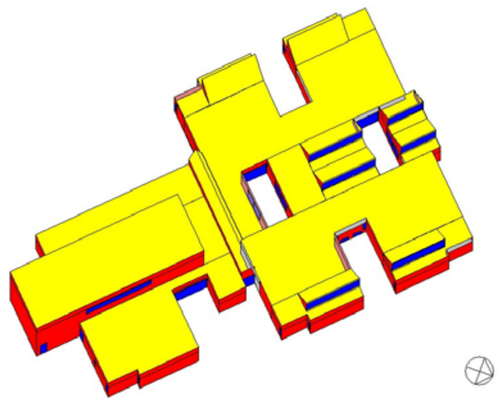


Figure 3.27- Clerestory 6 ft glazing case

(North side view)

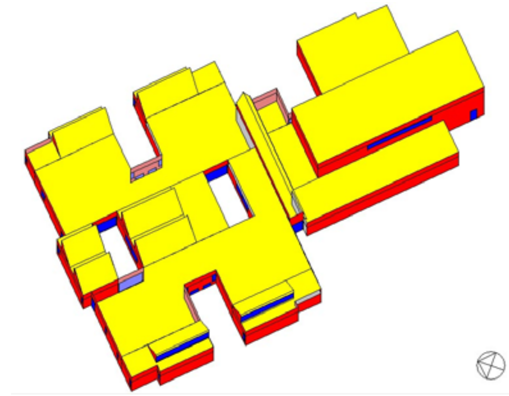


Figure 3.28- Clerestory 6 ft glazing case

(South side view)

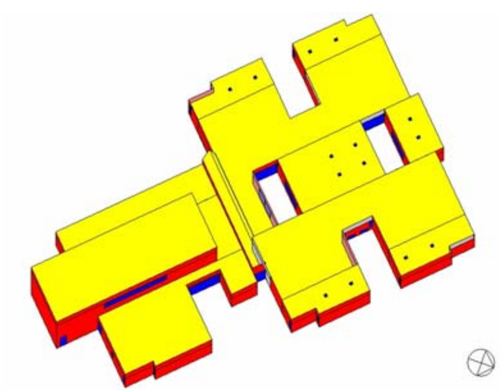


Figure 3.29- Skylight 1% glazing area

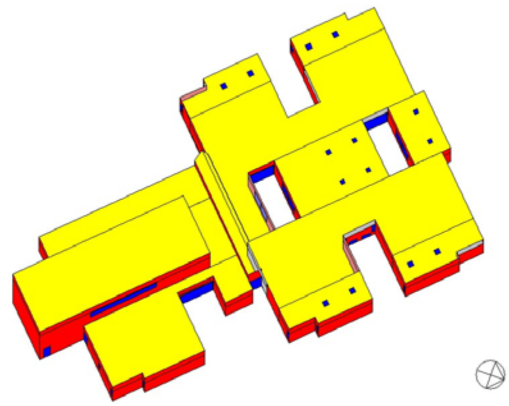


Figure 3.30- Skylight 3% glazing area

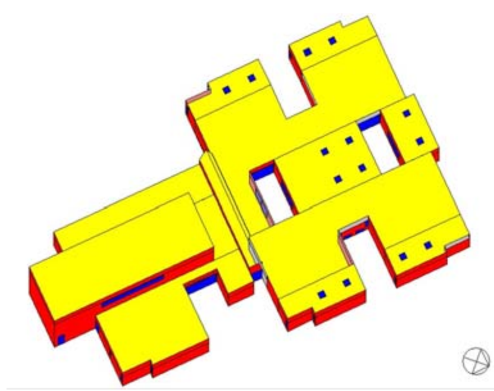


Figure 3.31- Skylight 5% glazing area

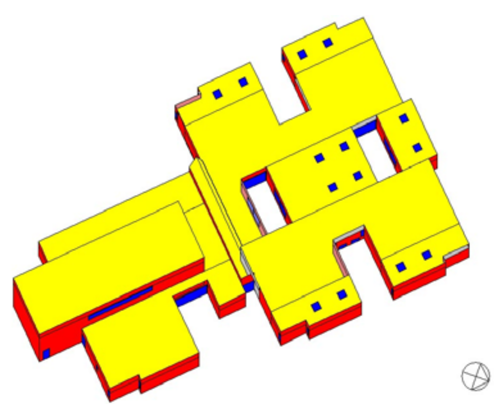


Figure 3.32- Skylight 7% glazing area

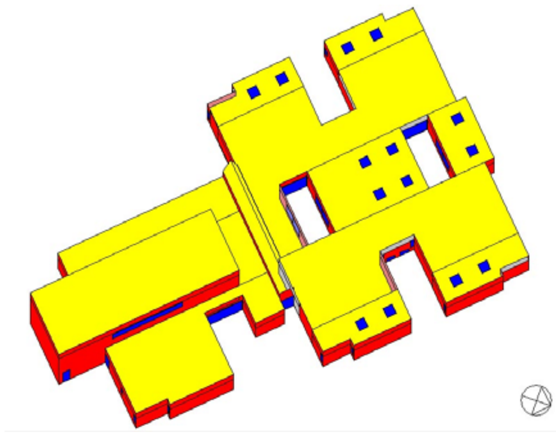


Figure 3.33- Skylight 10% glazing area

3.5.3. Light Sensor Positions

In order to record the daylighting levels inside the spaces, light sensor points (called light reference points in the DOE-2 simulation program) were introduced inside all the spaces. These sensors were typically located at a distance of 14 feet from the exterior wall and at 14 feet each from the other two side walls. Two reference points were specified for every space; a total of twelve (12) reference points for all the spaces combined. A DrawBDL representation of the sensor locations inside the spaces has been presented in Figure 3.34.

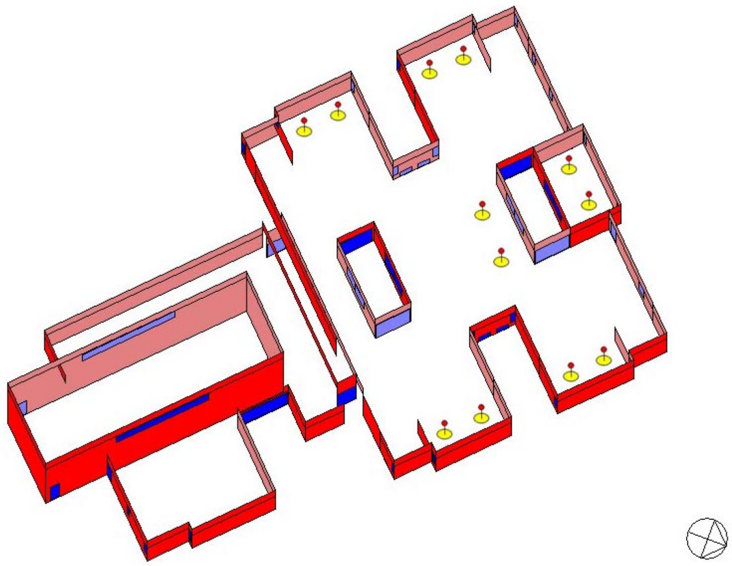


Figure 3.34- DrawBDL representation of the reference point positions in DOE-2.

3.5.4. Use of FUNCTION Input in DOE-2

The daylight factors obtained from DOE-2 for the skylight cases were found to show a big difference as compared to the daylight factors from the physical model. It was decided to consider the daylight factors from the physical model for further daylighting calculations in DOE-2. In order to use these factors in DOE-2, a special FORTRAN input was necessary to be added in the DOE-2 input file. This is called a FUNCTION in DOE-2, and this input code overwrites the daylight factors as calculated by DOE-2 and replaces them with custom daylight factor values as input by the user. In this case, the custom daylight factor values are the physical model values.

The input function feature allows the user to modify DOE-2 LOADS and SYSTEMS calculations without having to recompile the program. Input functions are input as small, FORTRAN-like routines that are included in the regular building description (DOE-2 Supplement Version 2.1 E 1993). The user has to specify the values and the exact position in the hourly simulation where they are to be applied by the program. 'Functions' are referenced within the hourly loop of the DOE-2 simulation, and hence are calculated for every hour of the simulation run period (DOE-2 Supplement Version 2.1 E 1993). The DOE-2.1 E Supplement includes the information necessary for the correct definitions of function inputs in DOE-2. The actual definition of a new FUNCTION was beyond the scope of this research, and hence a pre-defined function was use in the DOE-2 daylighting calculations.

The main commands and keywords associated with the functional input are: FUNCTION, FUNCTION NAME, ASSIGN, CALCULATE, and END-FUNCTION. The FUNCTION command defines the characteristics of the functional input. The 'Functions' must be defined after the END command, and before the COMPUTE LOADS or COMPUTE SYSTEMS commands in DOE-2 (DOE-2 Supplement Version 2.1 E 1993). The variables used within the FUNCTION command are defined through the ASSIGN command. Input statements to be used for defining the functions are stated under the CALCULATE command and all statements following this command have to begin in or after column 7. The final command is the END-FUNCTION command that informs DOE-2 that the functional input has ended (is complete). The DOE-2.1 E Supplement lists all the valid FORTRAN statements and operations that might be use for defining the function inputs. It also presents a number of examples that indicate the use of functional inputs.

The ‘LOADS Example 4’ in the DOE-2 Supplement details the use of a daylighting input function to include daylight factors calculated from physical model measurements. DAYL-ILLUM-FN is the special function used in this example. This function defines the hourly daylight illuminance values and glare indices at the specified reference points (light sensor positions) in a space. In this example, the coefficients obtained by the user from the physical scale model are multiplied by the hourly total exterior illuminance from sun and sky to give the interior daylight illuminance at the specified points. This leads to the overwriting of daylight factor values from DOE-2 through substitution of the newly calculated values. A variation of the procedure used in this example was used in this research. The actual function input used for this research is the one developed by M. Steven Baker from the Oregon Department of Energy. This functional input example was published in the Proceedings of the Solar Energy Society Conference held in Denver, Colorado in 1989. A total of two examples were discussed by Baker, the first one being for a north-facing perimeter space in the Emerald Public Utility District Building (EPUD) in Eugene, OR. In this example, daylighting was approximated as a fixed daylight factor times the outside horizontal illuminance. A factor of 0.80 was used to adjust the measured model data for losses in visible transmission through double-glazing used in the building. The daylight factor calculation shown in this method is similar to the one used in the current study, and hence a similar functional input was used, and a brief summary of the main commands in SPACE 1-1 (one of the spaces in the DOE-2 building input file) is presented here. Please note that the dollar sign ($) used in between the code is used as a comment delimiter in the DOE-2 input file.

```
$ The user-defined FUNCTION was input in the SPACE commands

INPUT LOADS  ..
.
.
SPACE1-1       =SPACE
.
.
DAYL-ILLUM-FN = (*NONE*,*F-1*)                              $ User defined
FUNCTION
.

END  ..
.
.
$ Next the daylighting FUNCTION was defined after the END command in LOADS and
variable names were defined. The variable names were same as DOE-2 global names


FUNCTION NAME=F-1

LEVEL=SPACE ..


ASSIGN   OHISKF=OHISKF
         CHISKF=CHISKF
         HISUNF=HISUNF
         ILLUM1=DAYLIGHT-ILLUM1   ..


$ OHISKF= Horizontal Illuminance from the overcast part of the sky
$ CHISKF= Horizontal Illuminance from the clear part of the sky
$ HISUNF = Horizontal Illuminance from sun
$ ILLUM1 = Daylight Illuminance at Reference point 1
```

```
$Next the calculation routine was defined. 0.01 is a value for measured daylight factor
from the physical scale model.

CALCULATE ..

      ILLUM1=0.80*(HISUNF+CHISKF+OHISKF)*0.01
      END

$The END-FUNCTION command completed the function input

END-FUNCTION ..

COMPUTE  LOADS  ..
```

A comparison of the DOE-2 output before and after the use of the FUNCTION command showed a distinct difference in electricity and natural gas consumption values for all the skylight cases when compared with the base case. The use of the command also indicated an increase in the percent lighting reduction and average illuminance (footcandles) values in all the spaces. Though an expensive tool at the student research level, the physical model proved to be very efficient in order to arrive at these results.

The methodology also involved the DOE-2 base case model calibration which was an important part of this research. The following section discusses the procedures involved in creating a base case DOE-2 energy simulation model for the case study building. Measured data and drawings were used to create a basic input file for the simulation, and this file was then modified through a number of alterations to different input parameters in order to match the simulated results to the actual measured data. The main basis for comparison was the monthly natural gas use and the hourly electricity use. No data was available for hourly natural gas use, and hence the calibration was limited to the monthly level. Graphical calibration analysis tools were used to visualize the effects of every new modification to the base case model, thus improving the overall accuracy of the calibration. A final calibrated model thus created was then considered as the reference case for all future simulations to study the effects of daylighting.

3.6. CALIBRATION OF THE DOE-2 BASE CASE SIMULATION

The comparison and modification process was repeated several times until an acceptable calibrated model with minimal amount of errors was developed.

The model calibration involved the following main steps:

- Basic simulation run with one VAV system without any heating system
- Basic simulation run with 3 systems (2 Variable Air Volume, 1 Multizone) and heating
- Use of the custom weighting factors (Floor-weight = 0)
- Use of the U-effective keyword
- Revised Multizone (MZS) system using defaults from the DOE-2 manual
- Revised heating and cooling set-point temperatures for the systems
- Occupancy, lighting, equipment schedules altered using typical weekday-weekend profiles based on actual schedules and hourly electricity use time-series plots.

The information regarding the functioning of the case-study school was used to prepare typical schedules for occupancy, lighting, and receptacle uses. Figure 3.35 shows a typical schedule used in the DOE-2 simulations. Though the schedules did not perfectly match existing conditions, they represented a typical weekday and weekend working for the school that was expected to fulfill the level of calibration for this research.

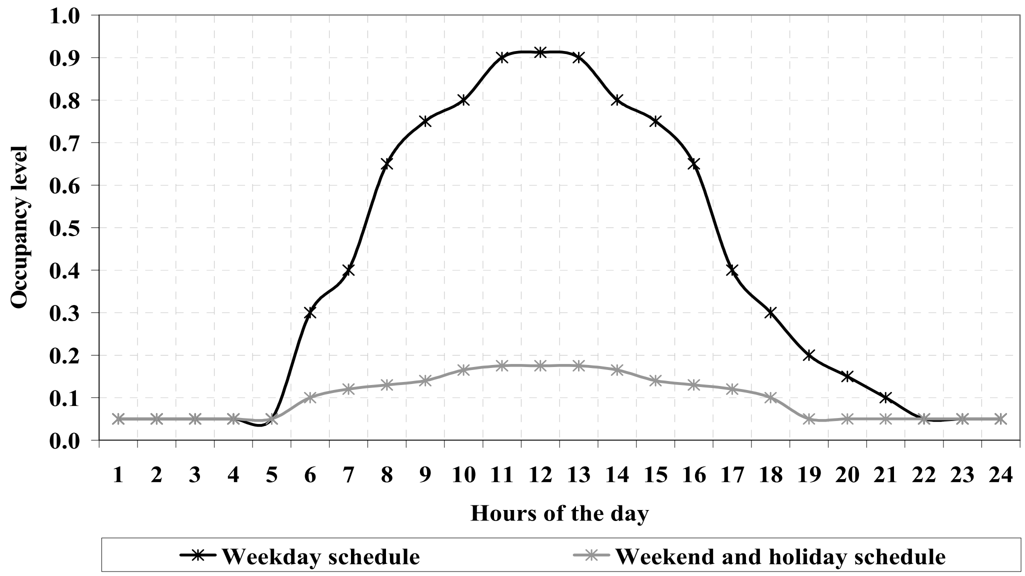


Figure 3.35 – Typical weekday and weekend schedule used for occupancy, lighting, and receptacle use in the DOE-2 simulation. On the y-axis, 0.0=completely unoccupied (zero occupancy), and 1.0=completely occupied (100% occupancy).

Previous research suggests that short-term monitored data can be used for long-term prediction of energy performance of commercial and institutional buildings (Abushakra 2001). To achieve calibration at the hourly level for whole building electricity use, an hourly time-series plot was developed for only the first six weeks of the year (January to mid-February) for the simulated case using the typical weekday-weekend schedule. This plot was then compared with the hourly electricity use profile for the first six weeks for the existing school building using measured data. A study of the existing hourly whole building electricity use indicated that the chiller was not in use for the first six weeks during the month of January and part of February due to low outdoor average dry bulb temperatures, and showed use after this period. The DOE-2 simulation for the base case was run without the chiller and pumps (only lighting, receptacle, and air-handling units electric consumption was used) to try and match the profile for the first six weeks. A comparison for this period was set as an indicator whether the model was calibrated at the hourly level.

Previous studies have indicated a relation between types of weather data used in DOE-2 simulation to their effect on energy uses (Haberl et al. 1993). The Houston TMY2 weather file was used for the DOE-2 simulation for the current study. As the study was conducted for College Station, Texas, it was felt important to compare the temperature profiles for the actual weather data for College Station and the typical weather data from the TMY2 file that would be used for the simulations. Figure 3.36 shows a comparison between the measured daily outdoor dry bulb temperatures obtained from the case study site and the ones from the Houston TMY2 weather file. The temperature profiles were found to fall within the same range of minimum and maximum values, but showed a lot of dissimilarities when analyzed at a daily level.

In order to indicate a calibration at the daily level, the actual daily whole building electricity use was plotted against the actual average daily dry bulb temperatures and the simulated daily whole building electricity use was plotted against the average daily dry bulb temperatures from the TMY2 file.

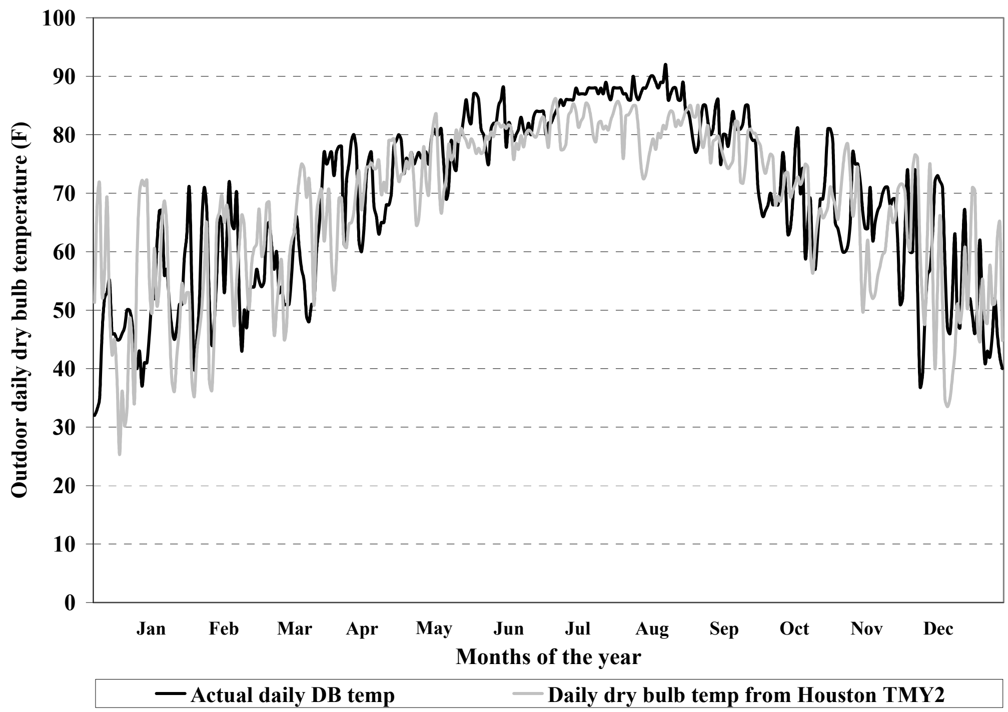


Figure 3.36 – Comparison between outdoor daily dry bulb temperatures from the actual school building and the Houston TMY2 weather file.

3.6.1. Use of Custom Weighting Factors and U-effective Keyword

In DOE-2, weighting-factors are assigned for all the spaces using the FLOOR-WEIGHT command. Standard ASHRAE weighting factors are 30, 70, and 130, for light, medium, and heavy construction. If no floor weight is specified in the input file, DOE-2 defaults to medium=70 (LBL 1993). Custom weighting factors can be assigned by the user, but the use of the FLOOR-WEIGHT=0 command automatically calculates and assigns custom values based on building material properties. The custom weighting factors account for the thermal lag in the heating and cooling of furnishings and structures (LBL 1980). Previous studies indicate that the use of this command directly affects the thermal performance and building energy use. Values of 0 and 70 were assigned and their effect on the electricity and natural gas use was analyzed for the case study building. Winkelmann (1998) from the Simulation Research Group at Lawrence Berkeley Laboratory has explained the use of the U-EFFECTIVE keyword in the UNDERGROUND-FLOOR command in order to achieve a correct calculation of heat transfer through underground surfaces (walls and floors in contact with the ground) in DOE-2. The equation used for the effective U-value is given as: Q= [U-EFFECTIVE]*A ($T_g - T_i$),

where A is the surface area, T_g is the ground temperature, and T_i is the inside air temperature. The effective U-values were calculated for all the underground floors in this research, and their use has been evaluated. Please refer to Appendix C where a detailed account of the calculation procedure has been presented. The effect of FLOOR-WEIGHT and U-EFFECTIVE commands was explored during the initial steps in model calibration.

3.6.2. Use of Graphical Analysis Techniques in Calibration

Graphical techniques were used to visualize goodness-of-fit between hourly measured and simulated electricity use. To better visualize a large number of data points, it becomes necessary to use three-dimensional and other types of intensive graphical software to judge the accuracy of the model (Haberl et al., 1988).

Haberl and Bou-Saada (1998) have explained different techniques to calibrate hourly building simulation models to measured building energy and environmental data.

The paper discusses various statistical and graphical methods that can be used by the DOE-2 user for calibration. Comparative 3-D Surface Plots has been stated as one of the efficient methods among the graphical calibration tools. Two-dimensional time series plots have been traditionally used for building energy calibration. But when it comes to plotting long-term hourly time-series data, this method can pose a problem (Haberl 1998). A direct comparison between every individual data point in the series is not possible at the 2 dimensional levels, and hence this technique becomes ineffective. The study by Haberl and Bou-Saada (1998) states that hourly differences occurring at the individual point level can be detected visually over the entire simulation process and this would allow the user to identify similar and dissimilar patterns in the comparisons. In order to create the 3-D surface plots, data analysis software is required. The program Microsoft Excel can handle huge amount of data and is an excellent tool to represent the DOE-2 output in a graphical manner. Hourly electric use output data from DOE-2 was imported into Microsoft Excel. In order to generate 3 dimensional plots, a special tool is needed that can perform the conversion of hourly columnar data into matrix output format. The program Colrow3D (Energy Systems Laboratory, Texas A&M University 1991) has been developed at the Energy Systems Laboratory which can recreate the said process. The program creates a *.3d file which can be opened through Microsoft Excel to create surface plots. The graphical method of calibration was found to be very effective in understanding the exact trend at the hourly level. 3-d plots for the case study site data and the DOE-2 simulated data were made for all the months of the year 2001.

3.6.3. Summary of Calibration

A reasonably good calibration was achieved for whole building electricity and natural gas use at the monthly and daily level, and electricity use (lighting, receptacle, and air-handling units) at the hourly level.

Cooling and heating energy use data for the case study building was unavailable for calibration. The simulated heating and cooling profiles have been generated for the model using DOE-2 and are presented in Appendix D of this thesis. Another factor that could have affected the calibration process would have been the availability of current on-site measured weather data for the simulation. This would include temperature and humidity data that could be used to pack a new weather tape for College Station in proper format for DOE-2. Measured data has been shown to improve accuracy of the simulation (Haberl 1995).

Occupancy, lighting, and equipment schedules played a very important part in model calibration. A common method followed to achieve hourly and daily calibration was superimposition of time-series plots. The hourly electricity use data from the case study site was superimposed onto the DOE-2 simulated data to visually detect differences. This was repeated after every schedule change or after any significant modification made to the input file. Macros were used in Microsoft Excel to extract the required daily and hourly data from the DOE-2 output file.

Though model calibration took up a considerable amount of time in this research, it was considered important in providing validity to future simulations and results. The graphs presented in this chapter are representative of the large number of graphs and plots generated in order to achieve the desired calibration.

3.7. ANALYSIS AND DECISIONS PROCESS

The calibrated model was used for future DOE-2 simulations. Based on the result of energy simulations, an optimum daylighting design can be suggested for the analysis spaces in the case study school building.

Building energy analysis included cooling, heating, lighting, whole building electricity and natural gas use analyses for the case study school building. Energy use reductions and energy cost savings were calculated for all the proposed daylighting design variants.

The analysis and results for the DOE-2 calibration, building energy use, and daylighting are presented in the following chapter.

CHAPTER IV

ANALYSIS AND RESULTS

Development of a recommended design is dependant on a subjective optimization between quality and quantity. This chapter summarizes the results of the daylighting and building energy analysis. It is comprised of four sections: 1) Results of the DOE-2 base case model calibration, 2) Daylighting Analysis, 3) Building Energy Analysis, and 4) Economics. The DOE-2 calibration presents the results of electricity use calibration at the hourly and daily level, and the natural gas use at the daily level. The daylighting analysis section explains the daylight factor measurements in the actual building space and physical scale model, and the daylight factor output obtained from the daylighting simulation in DOE-2. The respective values were analyzed for their trends to further validate the DOE-2 model. Selected daylight factors were then used for further analysis of daylight savings. The DOE-2 daylighting simulation output was used to analyze the percent energy reduction in all the spaces due to the application of daylighting. This led to an understanding of the potential of daylighting to reduce lighting energy use, thus effecting electricity cost savings. Another important consideration is the average illuminance (in footcandles) in the spaces due to daylighting. The results were important in determining the optimum range of skylights and clerestories that would satisfy daylight requirements in the classroom spaces in actual building. The building energy analysis focused on the comparisons in lighting, cooling, electricity, and natural gas use between the existing buildings as represented by the calibrated DOE-2 model and proposed daylighting options, and also between all the proposed skylight and clerestory cases. The last section of the chapter analyzes the energy savings and energy cost savings due to the use of daylighting. Among all the variants studied, a clerestory design with a 2 ft. high aperture was found to result in lowest energy cost.

4.1. RESULTS OF THE DOE-2 BASE CASE CALIBRATION

As stated in the methodology used for base case DOE-2 model calibration, to achieve calibration at the hourly level for lighting and receptacles electricity use, DOE-2 output was graphed as an hourly time-series plot for only the first six weeks of the year (January to mid-February) using the typical weekday-weekend schedule. This time period is justifiable for calibrating fore electricity usage in lighting because there is no cooling electricity usage during that tine period. This plot was then compared with the hourly electricity use profile for the first six weeks for the existing school building using measured data. Figure 4.1 shows the hourly whole building electricity use comparison for the first six weeks between the actual and simulated cases. A visual analysis of the comparison indicates a reasonably good calibration at the hourly level. The typical weekday-weekend schedules were used for all future simulations.

In order to indicate a calibration at the daily level, the actual daily whole building electricity use was plotted against the actual average daily dry bulb temperatures and the simulated daily whole building electricity use was plotted against the average daily dry bulb temperatures from the TMY2 file. This kind of a comparison was done in order to remove the effect of discrepancies between the two different weather data.

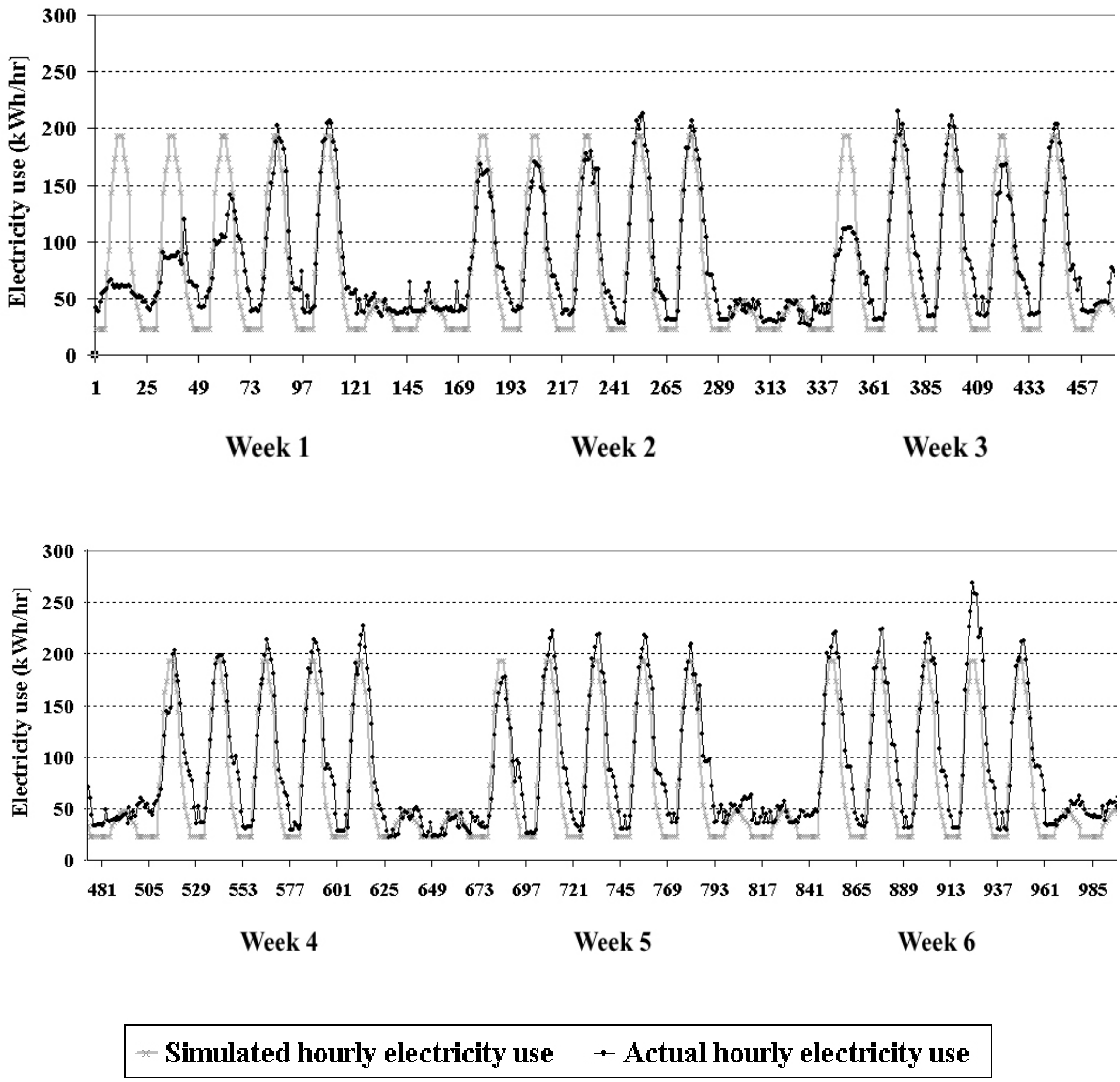


Figure 4.1 – Hourly whole building electricity use comparison for the first six weeks between the actual and simulated cases. The top plot shows the first three weeks (1-3) and the lower plot shows the next three weeks (4-6). The hours are plotted on the x-axis and the hourly electricity use on the y-axis.

Figures 4.2 and 4.3 show the daily electricity use comparison and the daily natural gas use comparisons respectively between the actual and simulated cases. The actual and simulated uses are plotted against their respective daily temperatures. The comparison indicates a reasonably good fit at the daily level of calibration. A similar comparison at the monthly level indicated similar electricity and natural gas use profiles for the actual and simulated cases, with a slightly better fit than at the daily level. The monthly comparisons have been presented in Appendix D of this thesis.

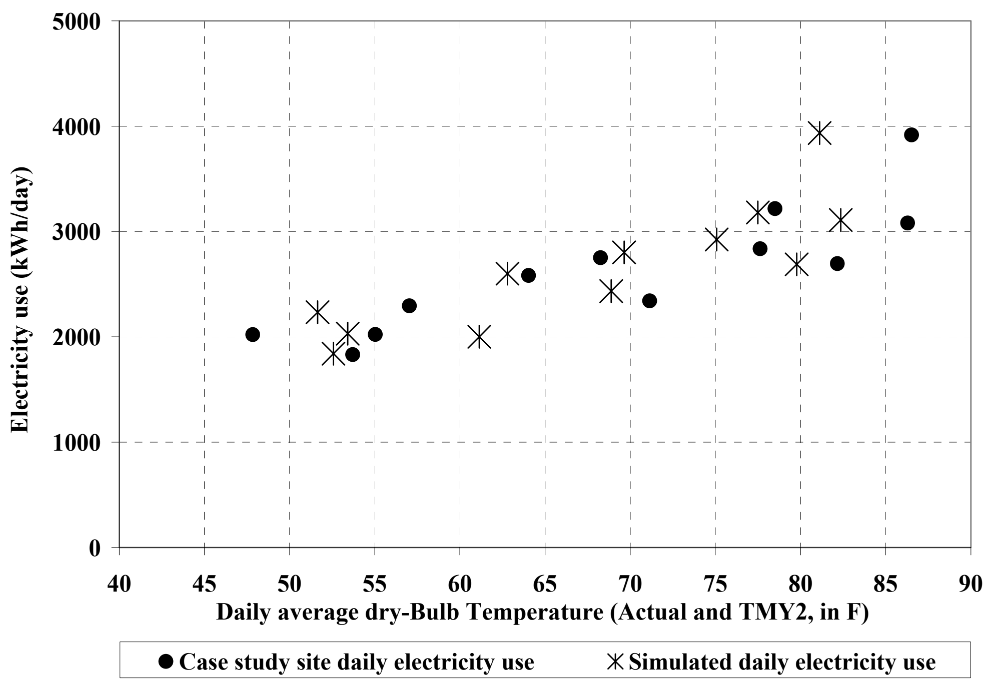


Figure 4.2 –Daily electricity use versus outdoor dry-bulb temperature for the case study site and simulated case.

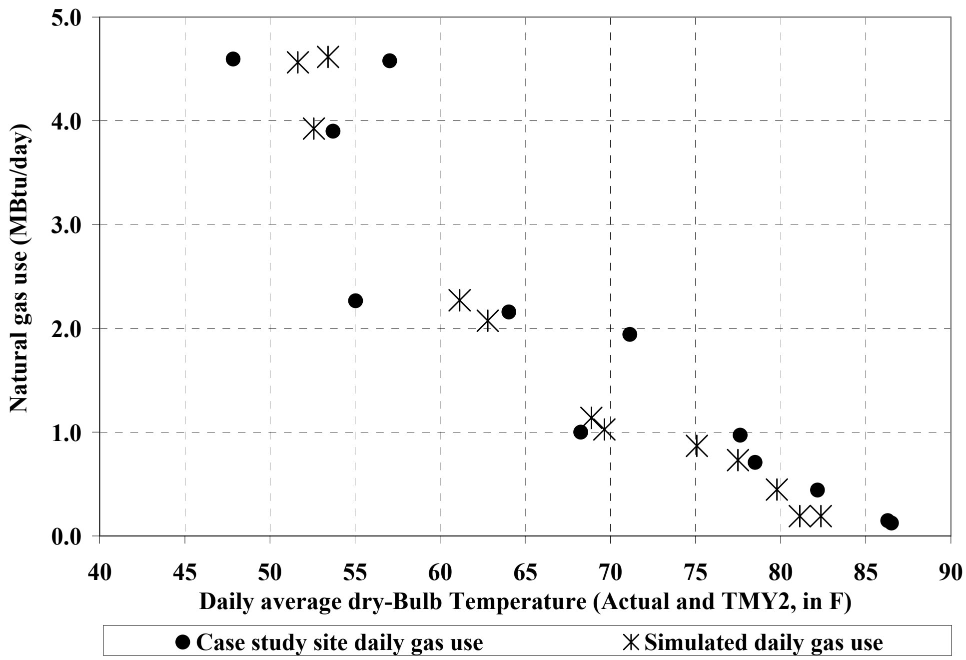


Figure 4.3 –Daily natural gas use versus outdoor dry-bulb temperature for the case study site and simulated case.

Figure 4.4 shows the comparison between the actual measured data case and the simulated case for the months of January and February. Figure 4.5 shows the positive-only values in 3-D of the case study site measured data subtracted from the DOE-2 simulated output data and Figure 4.6 shows the positive only values in 3-D of the DOE-2 simulated output data subtracted from the case study site measured data for the same two months. Figures 4.5 and 4.6 also show the comparison between the uncalibrated base case and the calibrated base cases. The plots for the other months are presented in Appendix B.

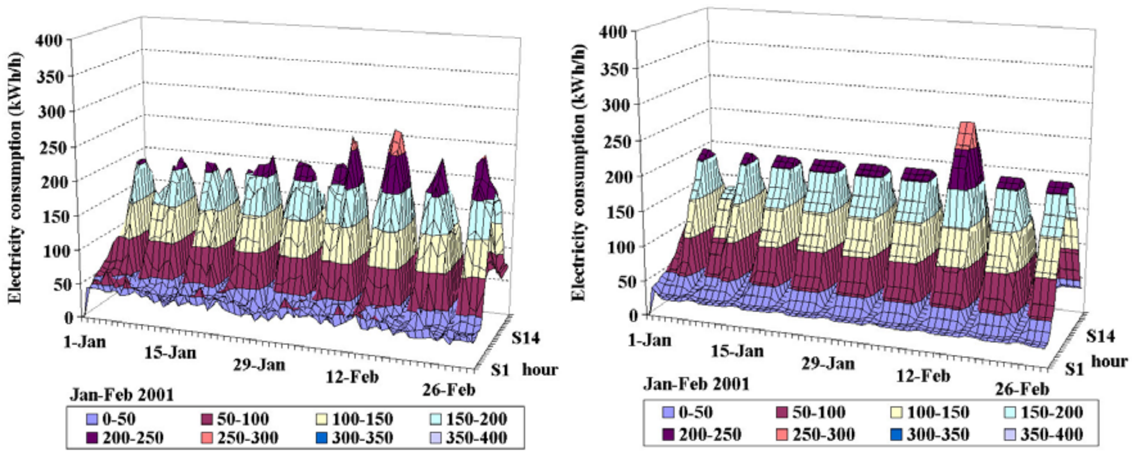


Figure 4.4 – 3-d surface plots showing measured and simulated total electricity use for the months of January and February.

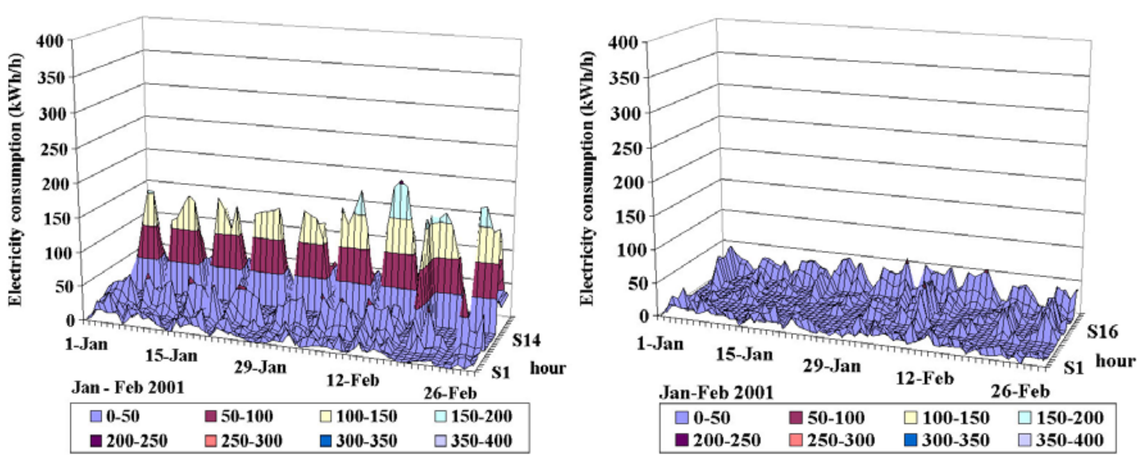


Figure 4.5 –Measured minus simulated electricity use for the months of January and February. (The plots indicate before and after calibration cases.)

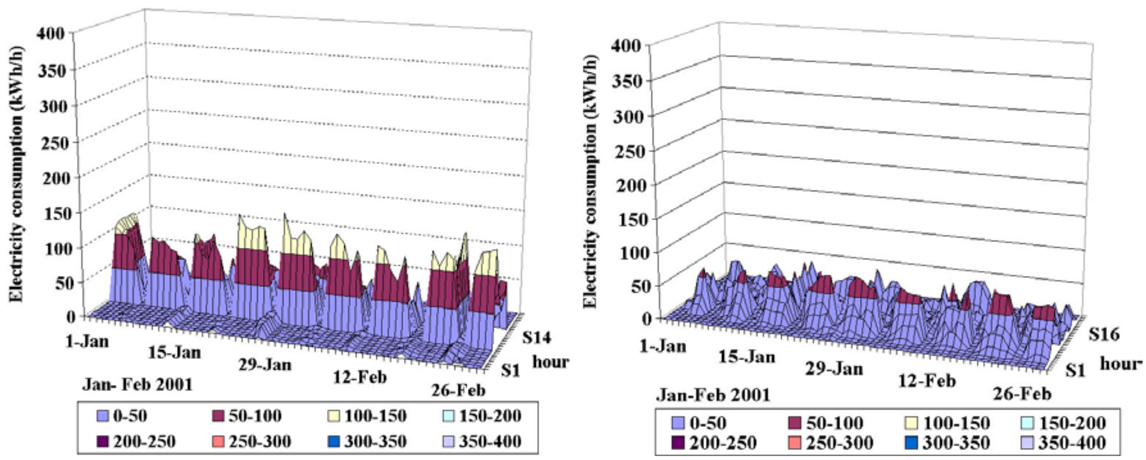


Figure 4.6 –Simulated minus measured electricity use for the months of January and February. (The plots indicate before and after calibration cases.)

Having achieved a calibrated simulation model of the building, the next step in the research was to generate and assess the expected performance of design variations. The remaining part of this chapter summarizes the results of the daylighting and building energy analysis.

4.2. DAYLIGHTING ANALYSIS

4.2.1. Daylight Factor Comparisons

This section of the chapter summarizes the daylight factors obtained from the physical model, the DOE-2 simulation, and the actual building. All daylight measurements were conducted during overcast sky conditions. A comparison of the daylight factors from the actual building, DOE-2, and the physical model indicate the trends observed. Table 4.1 and Figure 4.7 present the daylight factors for several analysis spaces (rooms).

Table 4.1 –Daylight factors from the actual building, DOE-2, and the physical scale model.

Base case		Daylight Factor (%) from the		
Location	**Light sensor**	**Actual building**	**DOE-2**	**Model**
Space 1-1	Ref Pt 1	0.058	0.33	0.33
	Ref Pt 2	0.209	0.34	0.35
Space 1-2	Ref Pt 1	0.171	0.34	0.33
	Ref Pt 2	0.042	0.33	0.35
Space 1-4	Ref Pt 1	0.077	0.55	
	Ref Pt 2	0.229	0.69	
Space 1-5	Ref Pt 1	0.026	0.22	0.37
	Ref Pt 2	0.126	0.2	0.39
Space 1-7	Ref Pt 1	0.201	0.29	0.37
	Ref Pt 2	0.245	0.32	0.41
Space 1-8	Ref Pt 1	0.263	0.36	0.37
	Ref Pt 2	0.255	0.35	0.41

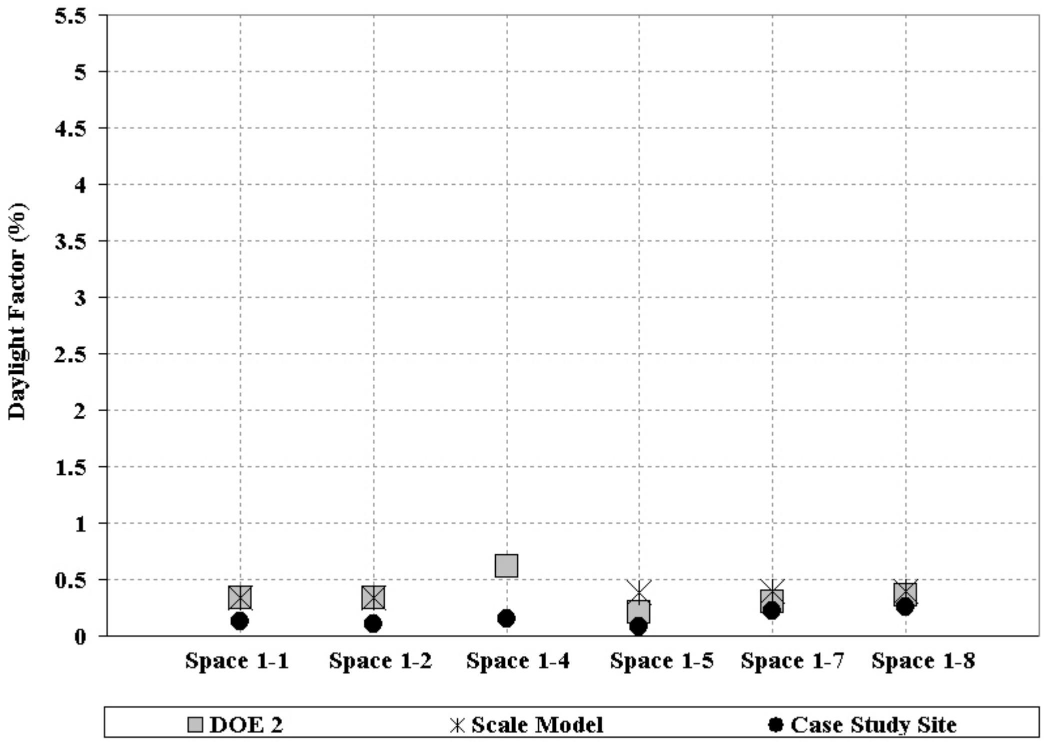


Figure 4.7 – Comparison of daylight factors from the actual building, physical scale model, and DOE-2.

As can be seen from the above table and figure, the respective daylight factors obtained from the physical model and DOE-2 for Spaces 1-1, 1-2, 1-7, and 1-8 are similar in values. Daylight factor from the physical model for Space 1-4 shows a value of zero as a model for this space was not constructed for experiment. The daylight factors from the actual building were consistently lower than the DOE-2 and physical model values. This can be attributed to various conditions in the case study spaces, the main one being the presence of ceiling-hung television sets near the window openings, which reduce the percent of daylight reaching the interiors. Other factors like the actual window transmittances, internal light reflections due to furniture and blackboards inside the classrooms, and the presence of trees outside the spaces could also reduce the interior daylight illuminance, thus reducing the overall daylight quality. Since daylight factor calculation in DOE-2 was found to be inaccurate, physical model values were incorporated into the DOE-2 model and used for further analysis.

The second part of the daylight factor analysis involved a comparison between the DOE-2 values and the physical model values for the proposed skylight and clerestory designs. Daylight factors obtained from DOE-2 and the physical model for the different skylight cases are presented in Table 4.2 and respective values for the different clerestory cases are presented in Table 4.3.

Table 4.2 – Daylight factors obtained from DOE-2 and the physical model for the different skylight cases.

Skylights	Daylight Factors (%)						
Location	**Light**	**Skylight 1%**		**Skylight 3%**		**Skylight 5%**	
	Sensor	**DOE-2**	**Model**	**DOE-2**	**Model**	**DOE-2**	**Model**
Space 1-1	Ref Pt 1	0.39	1.13	0.56	1.72	0.83	2.5
	Ref Pt 2	0.42	0.68	0.57	1.43	0.85	1.91
Space 1-2	Ref Pt 1	0.42	1.13	0.56	1.72	0.83	2.5
	Ref Pt 2	0.39	0.68	0.57	1.43	0.86	1.91
Space 1-4	Ref Pt 1	0.57		0.57		0.68	
	Ref Pt 2	0.71		0.71		0.82	
Space 1-5	Ref Pt 1	0.25	1.12	0.35	1.45	0.47	1.93
	Ref Pt 2	0.23	1.24	0.33	1.73	0.45	1.97
Space 1-7	Ref Pt 1	0.35	1.15	0.51	1.88	0.78	2.11
	Ref Pt 2	0.38	1.11	0.56	1.83	0.84	2.51
Space 1-8	Ref Pt 1	0.42	1.15	0.51	1.88	0.78	2.11
	Ref Pt 2	0.41	1.11	0.57	1.83	0.84	2.51

Table 4.2 – Continued

Skylights		Daylight Factors (%)			
Location	**Light**	**Skylight 7%**		**Skylight 10%**	
	Sensor	**DOE-2**	**Model**	**DOE-2**	**Model**
Space 1-1	Ref Pt 1	1.21	3.75	1.75	5.37
	Ref Pt 2	1.25	3.11	1.79	4.63
Space 1-2	Ref Pt 1	1.21	3.75	1.75	5.37
	Ref Pt 2	1.25	3.11	1.89	4.63
Space 1-4	Ref Pt 1	0.83		1.03	
	Ref Pt 2	0.98		1.22	
Space 1-5	Ref Pt 1	0.83	3.23	1.35	5.12
	Ref Pt 2	0.85	3.19	1.41	5.13
Space 1-7	Ref Pt 1	1.15	3.77	1.67	5.47
	Ref Pt 2	1.21	3.32	1.75	5.13
Space 1-8	Ref Pt 1	1.16	3.77	1.67	5.47
	Ref Pt 2	1.22	3.32	1.75	5.13

Table 4.3 – Daylight factors obtained from DOE-2 and the physical model for the different clerestory cases.

Clerestories		Daylight Factors (%)					
Location	**Light**	**Clearstory 2ft**		**Clearstory 4ft**		**Clearstory 6ft**	
	Sensor	**DOE-2**	**Model**	**DOE-2**	**Model**	**DOE-2**	**Model**
Space 1-1	Ref Pt 1	1.11	0.99	3.54	2.4	4.64	3.83
	Ref Pt 2	1.12	1.16	3.53	2.1	4.63	3.3
Space 1-2	Ref Pt 1	1.12	0.99	3.53	2.4	4.64	3.83
	Ref Pt 2	1.11	1.16	3.54	2.1	4.63	3.3
Space 1-4	Ref Pt 1	2.79		4.24		4.24	
	Ref Pt 2	2.46		4.11		4.11	
Space 1-5	Ref Pt 1	2.5		4.23		5.33	
	Ref Pt 2	2.04		4.01		5.32	
Space 1-7	Ref Pt 1	1.86	1.71	3.09	3.7	4.07	5.6
	Ref Pt 2	1.88	1.6	3.11	2.91	4.08	4.2
Space 1-8	Ref Pt 1	1.87	1.72	3.1	3.7	4.08	5.6
	Ref Pt 2	1.87	1.6	3.1	2.91	4.07	4.2

Figure 4.8 shows the daylight factor comparison between the daylight factors from DOE-2 and the physical model for the 1% skylight case, while Figure 4.9 shows a similar comparison for the 10% skylight case. The daylight factors obtained from the physical model were found to be much more than the factors from DOE-2 in both the cases. The difference showed an increase of approximately 2 times in the 1% daylight case and approximately 4 times more in the 10% daylight case. This comparison led to the conclusion that DOE-2 calculated daylight factors for the skylight cases were inaccurate. The daylight factors obtained from the physical scale model were used for further daylighting calculations.

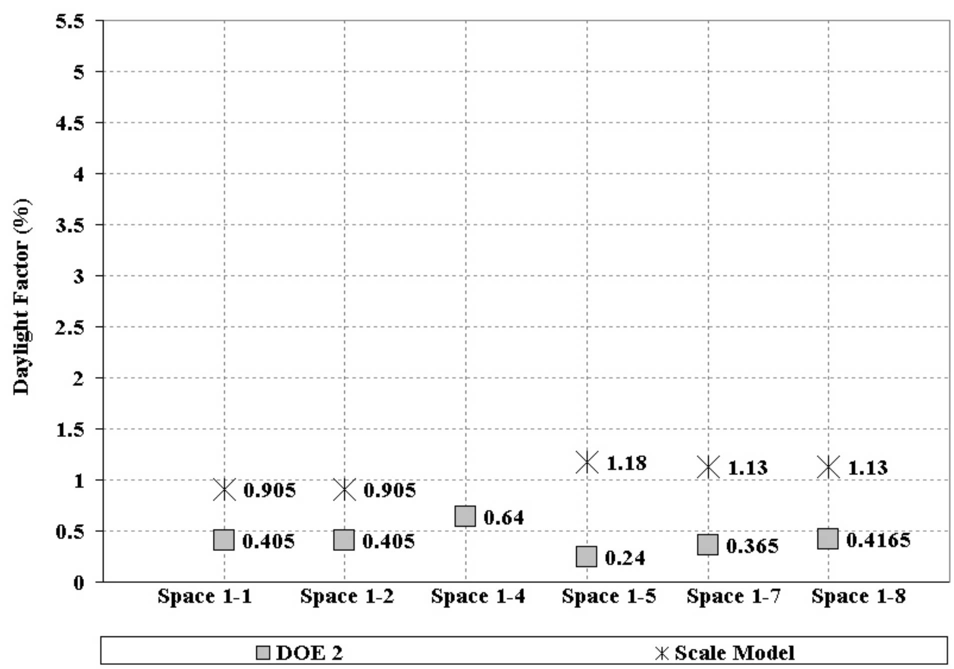


Figure 4.8 –Comparison between the daylight factors from DOE-2 and the physical model for the 1% skylight to roof area case.

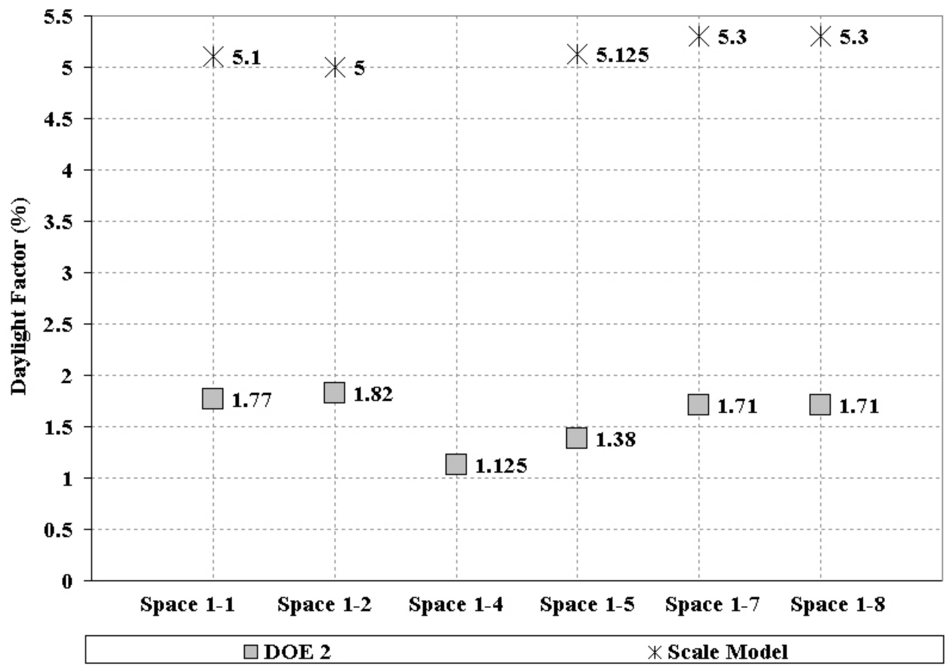


Figure 4.9 –Comparison between the daylight factors from DOE-2 and the physical model for the 10% skylight to roof area case.

Figure 4.10 shows the daylight factor comparison between the daylight factors from DOE-2 and the physical model for the 2 ft high clerestory case, while Figure 4.11 shows a similar comparison for the 6 ft high clerestory case. The daylight factors obtained from the physical model were found to be of similar value to the factors from DOE-2 in the 2 ft case, although the DOE-2 calculated daylight factors were larger. The daylight factors for the 6 ft case showed a difference between DOE-2 and the physical model. The DOE-2 calculated daylight factors showed a irregular trend and were termed inaccurate in determining the real percentage of daylight available inside the analysis spaces. The daylight factors obtained from the model were incorporated in DOE-2 and used for further analysis.

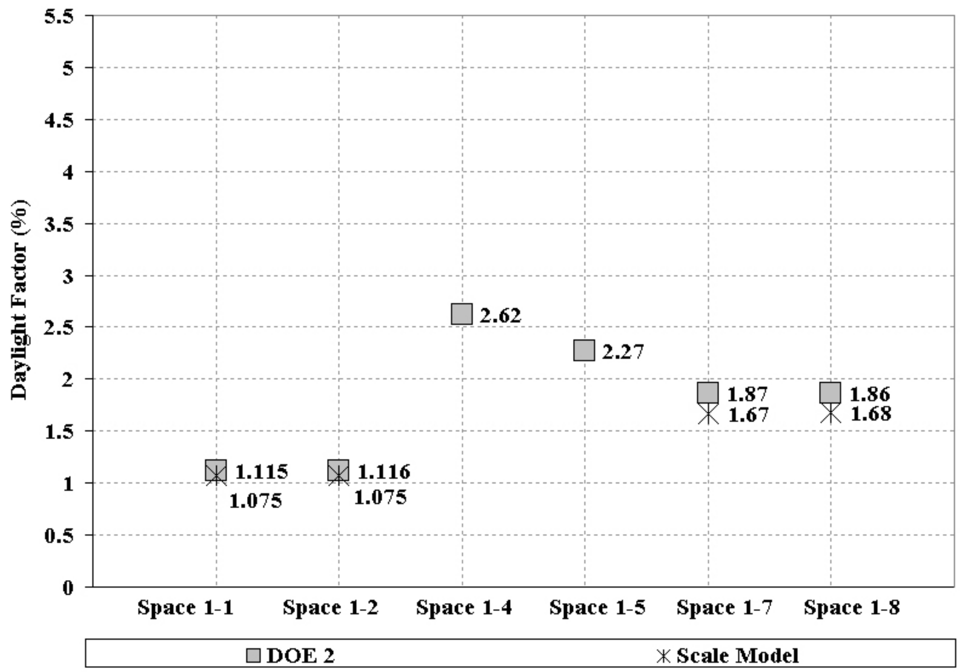


Figure 4.10–Comparison between the daylight factors from DOE-2 and the physical model for the 2 ft clerestory glazing height case.

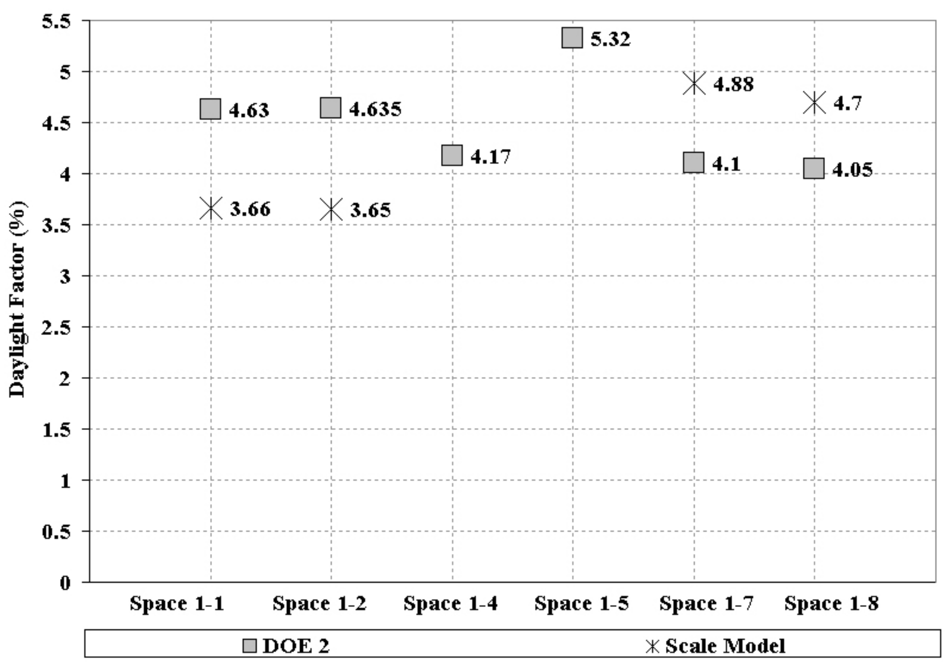


Figure 4.11 –Comparison between the daylight factors from DOE-2 and the physical model for the 6 ft clerestory glazing height case.

The increase in daylight factor values between the base case and the daylit skylighting and clerestory cases have been presented in Figure 4.12 and Figure 4.13. A 10% skylight case was shown to produce the highest daylight factors among all the cases studied, followed by the 6 ft clerestory case. In the skylight cases, skylight areas between 3% and 5% of the roof area were found to produce average daylight factors between 1.6 and 2 percent respectively, and were suggested as ideal for classroom-like spaces in the school. In the clerestory cases, glazing heights between 2 ft and 4 ft were found to produce average daylight factors between 1.8 and 3 percent respectively, and were suggested as ideal for classroom-like spaces in the school.

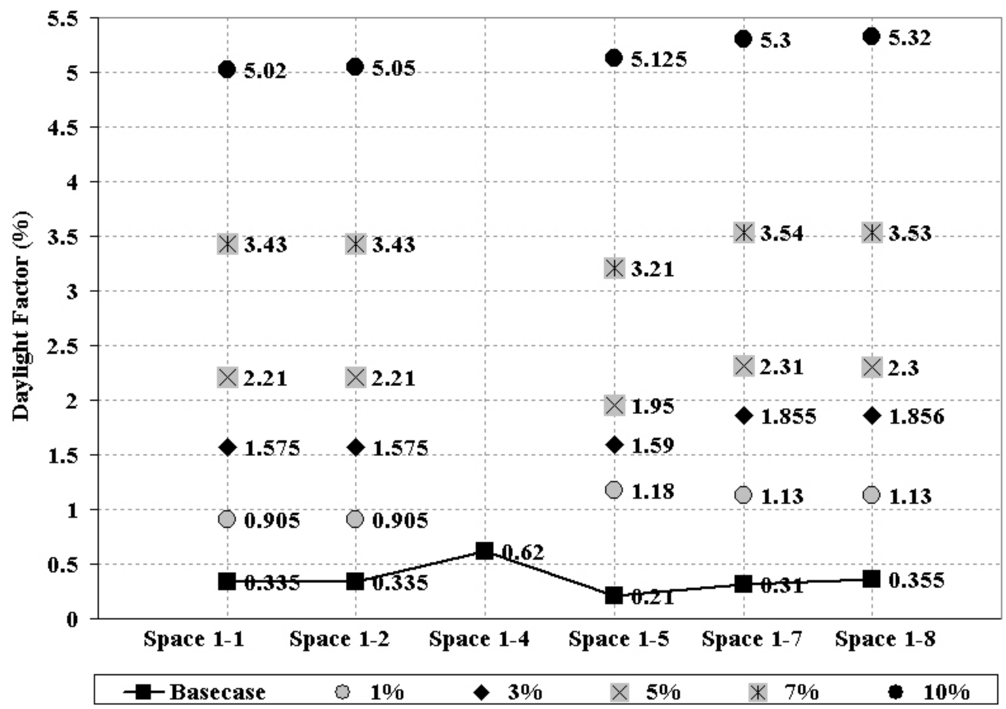


Figure 4.12 –Comparison of the daylight factors between the base case and the different skylight cases.

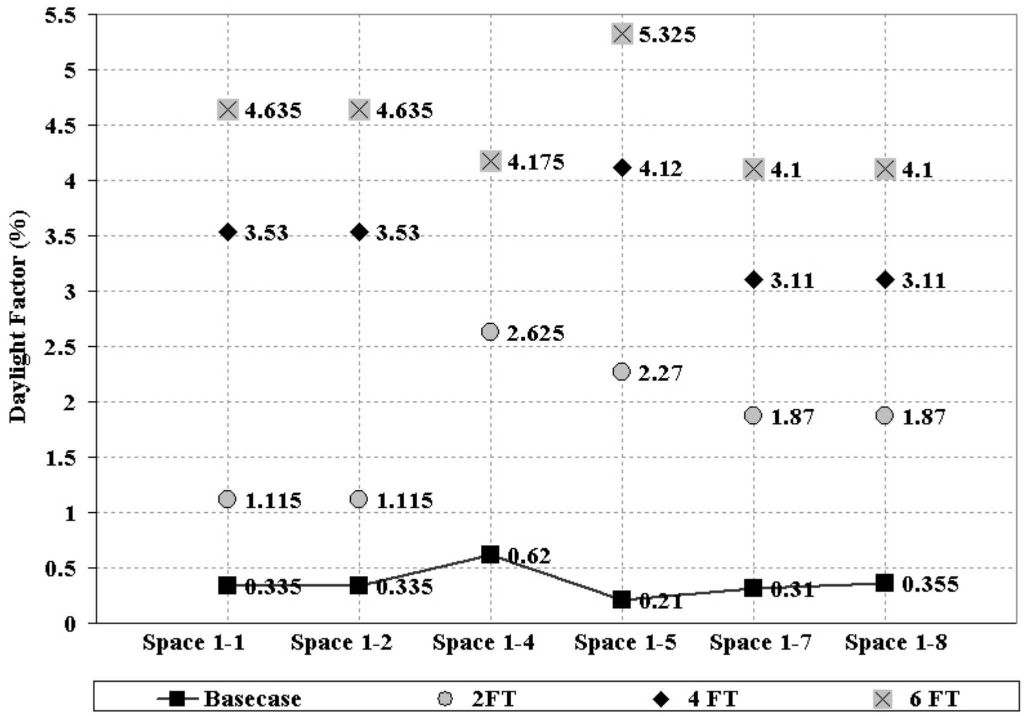


Figure 4.13 –Comparison of the daylight factors between the base case and the different clerestory cases.

4.2.2. Space Daylighting Summary

4.2.2.1. Percent Lighting Energy Reduction due to Daylighting

The daylighting output from the LOADS part of the DOE-2 simulation program was studied to compare the percent lighting energy reduction through the use of daylighting in the different spaces. Table 4.4 presents the data as obtained from the 'Space Daylighting Report': Report LS-G from the DOE-2 daylighting output. Figure 4.14 and Figure 4.15 shows the respective trends in lighting energy reduction for the proposed skylight and clerestory cases. Average lighting energy reductions of 48% and 57% were observed for the skylight and clerestory cases respectively. The lighting energy reductions as compared to the DOE-2 base case with daylighting were 26% and 33% for the skylight and clerestory cases respectively.

Table 4.4 – Percent lighting energy reduction due to daylighting for the different skylight and clerestory cases.

		Skylights: percentage glazing to roof area				
Location	**Base case**	**1%**	**3%**	**5%**	**7%**	**10%**
SPACE 1-1	25.2	37.9	48.8	53.3	57.1	59
SPACE 1-2	21.8	37.9	48.8	53.3	57.1	59
SPACE 1-4	34.9	38.2	50	54.6	57.4	59
SPACE 1-5	12.3	38.5	50.8	53.8	57.1	59
SPACE 1-7	20.7	37.9	48.8	53.3	57.1	59
SPACE 1-8	25.7	37.9	48.8	53.3	57.1	59
		Clerestories: height of glazing area				
Location	**Base case**	**2FT**	**3FT**	**4FT**	**5FT**	**6FT**
SPACE 1-1	25.2	54.4	56.8	58.1	58.9	59.4
SPACE 1-2	21.8	53.7	56.6	58	58.8	59.3
SPACE 1-4	34.9	57.2	58.9	59.8	60	60.6
SPACE 1-5	12.3	55	58	59.3	60	60.4
SPACE 1-7	20.7	52.5	55.2	56.6	57.5	58.1
SPACE 1-8	25.7	54	56	57.4	58.1	58.6

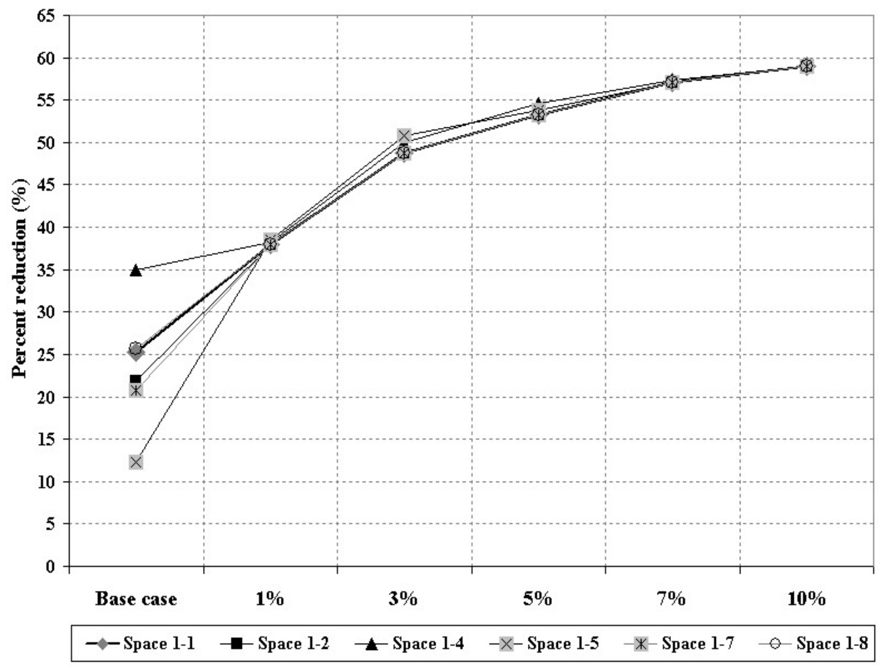


Figure 4.14 – Percent lighting energy reduction due to daylighting for the different skylight cases.

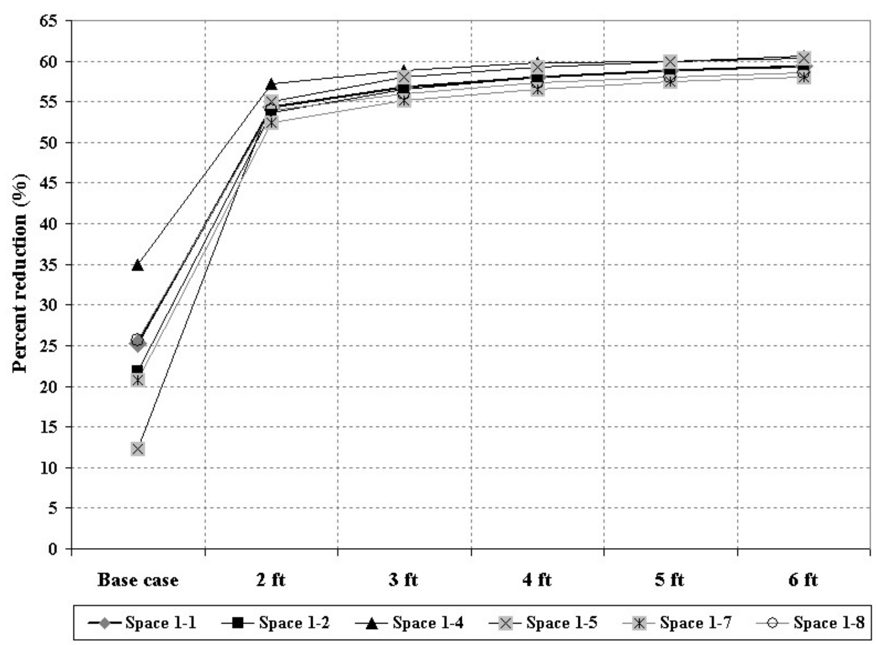


Figure 4.15 – Percent lighting energy reduction due to daylighting for the different clerestory cases.

Table 4.5 – Glazing area per space for all the proposed cases.

Location	Skylight Glazing Area per space (sq.ft)				
	1%	3%	5%	7%	10%
Space 1-1	18	52	88	124	176
Space 1-2	18	52	88	124	176
Space 1-4	32	96	164	228	324
Space 1-5	16	48	82	114	162
Space 1-7	18	52	88	124	176
Space 1-8	18	52	88	124	176
Location	**Clerestory Glazing Area per space (sq.ft)**				
	2 FT	**3 FT**	**4 FT**	**5 FT**	**6 FT**
Space 1-1	118	177	236	295	354
Space 1-2	118	177	236	295	354
Space 1-4	236	354	472	590	708
Space 1-5	118	177	236	295	354
Space 1-7	118	177	236	295	354
Space 1-8	118	177	236	295	354

4.2.2.2. Space Average Illuminance

The daylighting output from the DOE-2 simulation program was studied to compare the average illuminance (FC) through the use of daylighting in the different spaces. Table 4.6 presents the data as obtained from the 'Space Daylighting Report': Report LS-G from the DOE-2 daylighting output. Figure 4.16 and Figure 4.17 shows the respective trends in the increase in space average illuminance for the proposed skylight and clerestory cases. Average space illuminance values of 76 footcandles and 80 footcandles were observed for the skylight and clerestory cases respectively. The increase in the average space illuminance (all spaces included) was 44 and 47 footcandles for the skylight and clerestory cases respectively as compared to the DOE-2 base case with daylighting.

Table 4.6 – Space average illuminance values in footcandles for the different skylight and clerestory cases.

		Skylights: percentage glazing to roof area				
Location	**Base case**	**1%**	**3%**	**5%**	**7%**	**10%**
Space 1-1	14.5	25.3	44	61.2	95.4	139.1
Space 1-2	13.3	25.3	44	61.2	95.4	139.1
Space 1-4	18.7	25.6	47.3	69.6	100.2	139.1
Space 1-5	7.9	25.9	50.1	64	95.4	139.1
Space 1-7	12.4	25.3	44	61.2	95.4	139.1
Space 1-8	14.9	25.3	44	61.2	95.4	139.1

		Clerestories: height of glazing area				
Location	**Base case**	**2FT**	**3FT**	**4FT**	**5FT**	**6FT**
Space 1-1	25.2	43.7	55	66	75.8	84.7
Space 1-2	21.8	42.3	54	65	74.8	83.8
Space 1-4	34.9	74.4	80	100.1	105.5	121
Space 1-5	12.3	48.5	65	82.3	97.3	110.3
Space 1-7	20.7	44.5	58	70.4	100	110.6
Space 1-8	25.7	48	62	75.2	105.7	117.2

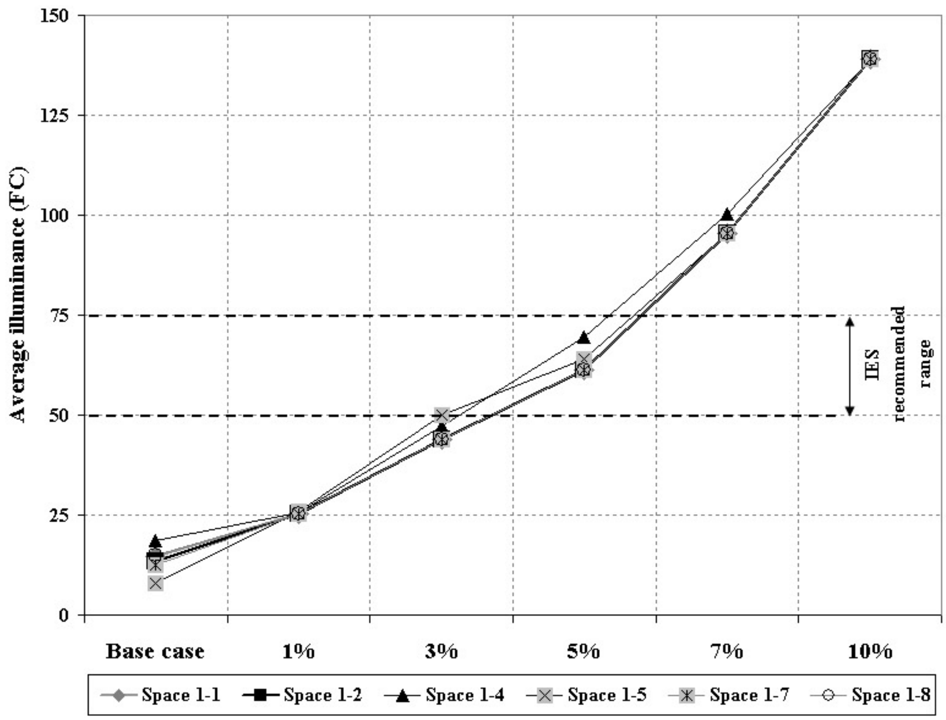


Figure 4.16 – Space average illuminance values for the different skylight cases.

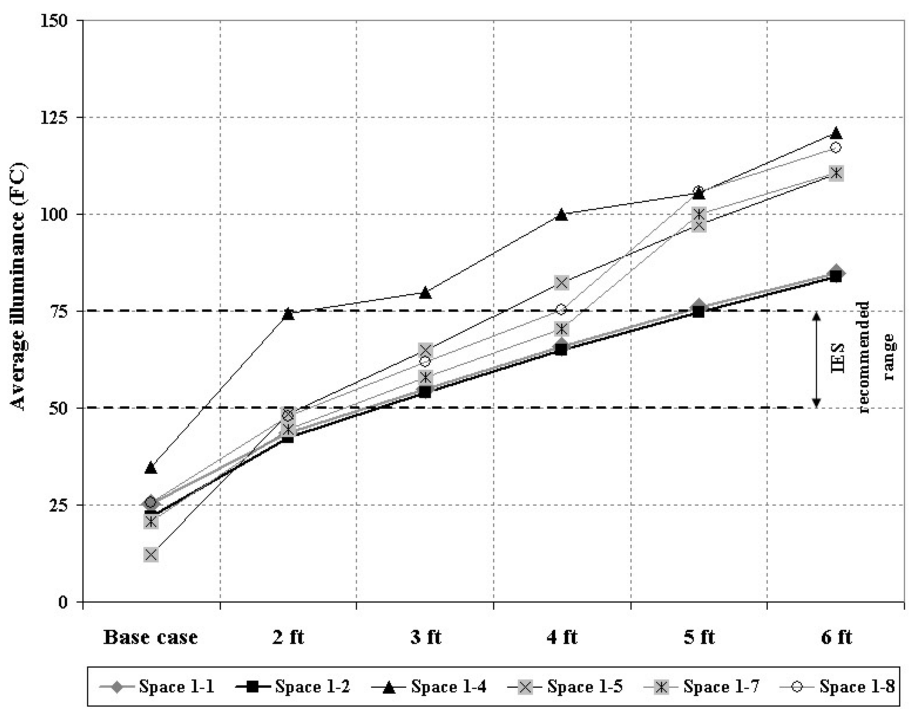


Figure 4.17 – Space average illuminance values for the different clerestory cases.

4.3. BUILDING ENERGY ANALYSIS

4.3.1. Calibrated DOE-2 Base Case With and Without Daylighting

This section discusses the effect of daylighting on the energy consumption of the school. In order to study the effect of daylighting, the calibrated base case DOE-2 simulation model was modified to utilize the daylighting commands. The daylighting commands were input inside the SPACE command, and included specifying the use of daylighting, number and nomenclature of the light-reference-points inside the space, fraction of the zone per reference point, light control type, and maximum allowable glare. The DOE-2 simulation program calculates the daylight factors and illuminance values at the specified reference points as has been discussed earlier in this chapter, and also calculates the electric and gas consumption for the building. A comparison of the daylit and non-daylit DOE-2 models can assist in understanding the exact nature of daylighting and its effect on energy consumption.

4.3.1.1. Lighting and Cooling Energy

Figures 4.18 – 4.19 and Table 4.7 present the monthly comparisons between the base case model without daylighting and base case model with daylighting to study the trends in lighting and cooling electric consumption throughout the year. The 'base case' used in all the analyses presented in the following graphs refers to the DOE-2 'calibrated base case', except mentioned otherwise.

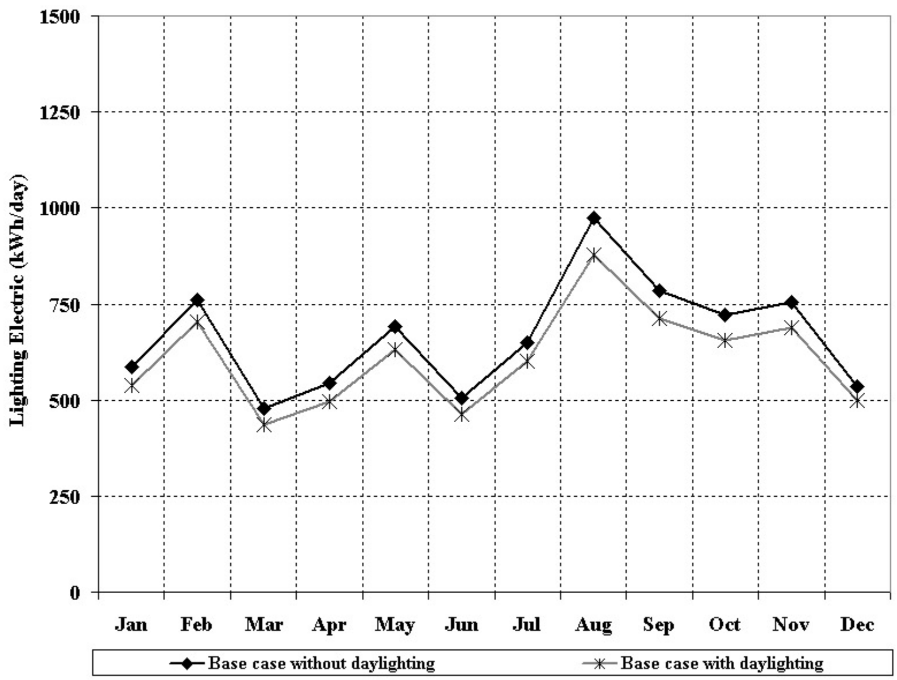


Figure 4.18 – Monthly lighting electricity use comparison between the base case model without daylighting and base case model with daylighting.

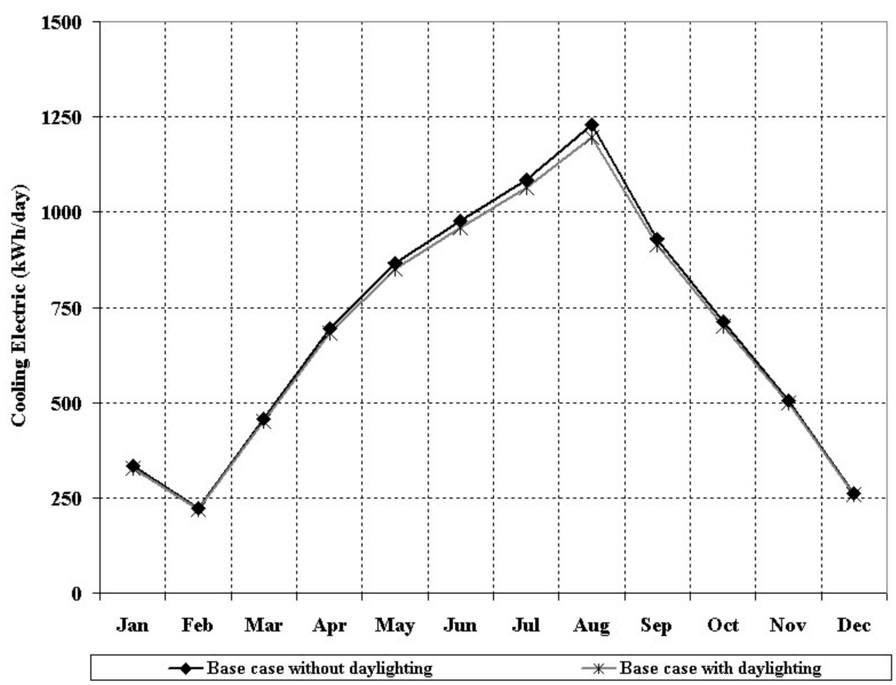


Figure 4.19 – Monthly cooling electricity use comparison between the base case model without daylighting and base case model with daylighting.

Table 4.7 – Monthly lighting and cooling electricity use comparison between the base case model without daylighting and base case model with daylighting.

Base case without daylighting						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Lighting (kWh/day)	585.1	760.8	477.0	544.8	692.7	505.4
Cooling (kWh/day)	333.1	222.5	457.4	693.4	866.5	977.0
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Lighting (kWh/day)	650.4	974.1	785.9	720.6	754.0	536.0
Cooling (kWh/day)	1085.6	1230.5	930.2	712.2	505.9	261.5
Base case with daylighting						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Lighting (kWh/day)	538.3	702.5	435.2	496.3	630.4	463.2
Cooling (kWh/day)	327.4	219.2	449.9	681.0	850.1	959.4
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Lighting (kWh/day)	600.1	877.5	712.2	655.5	689.3	500.2
Cooling (kWh/day)	1063.2	1195.8	913.1	700.0	497.7	257.3

The plots for lighting and cooling electric energy indicated that the model with proposed daylighting brought about a decrease in lighting energy throughout the year, whereas the cooling energy also decreased, especially in the hot season between the months of April to October. The reduction in lighting energy is more pronounced than the reduction in cooling energy.

4.3.1.2. Whole Building Electric and Heating Energy

The lighting and cooling electric energy use has a direct effect on the whole building electric and heating energy use. After studying the trends in cooling and lighting electricity uses, the analysis compared the whole building electricity and total heating energy uses for the two base cases.

Figures 4.20 – 4.23 and Table 4.8 present the monthly comparisons between the base case model without daylighting and base case model with daylighting to study the trends in whole building electric and heating fuel (natural gas) consumption throughout the year. The plots for whole building electric and heating energy indicated that the model with proposed daylighting brought about a decrease in electrical energy throughout the year, but the heating energy did not show an increase for any month.

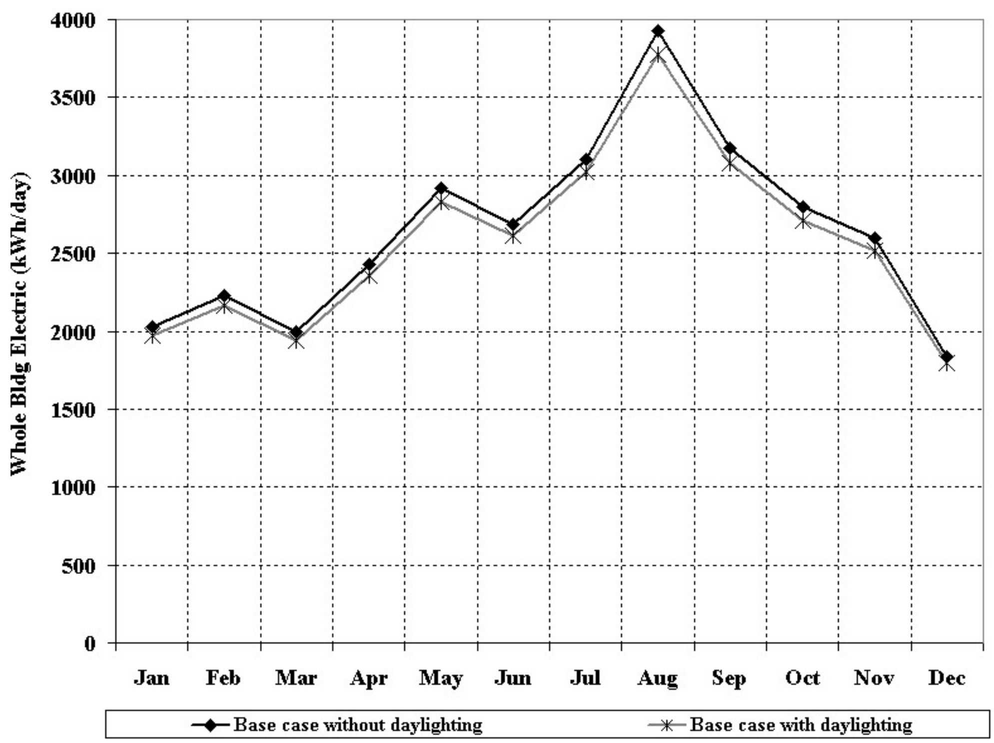


Figure 4.20 – Monthly whole building electricity use comparison between the base case model without daylighting and base case model with daylighting.

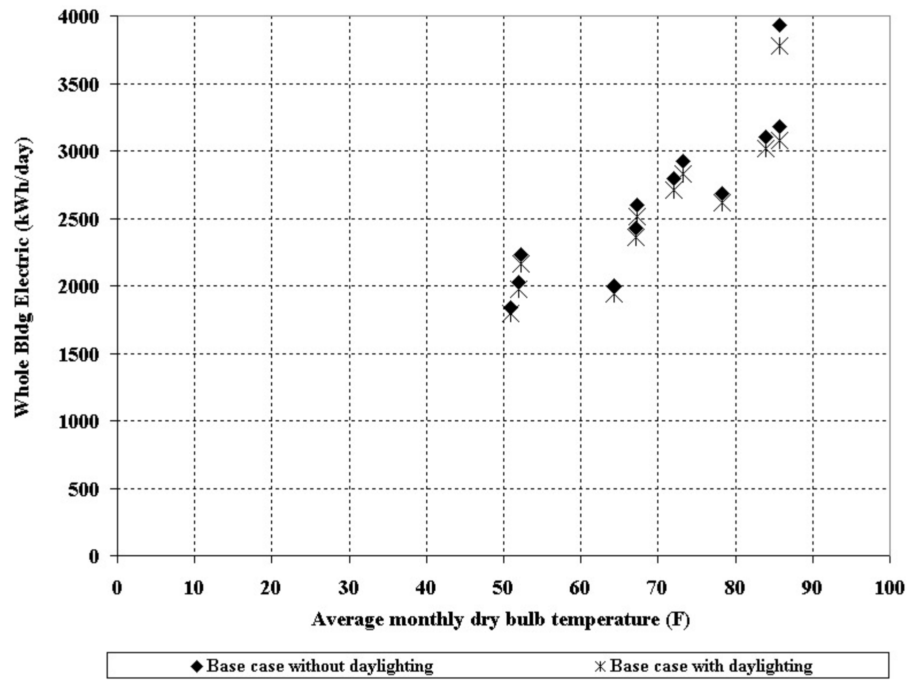


Figure 4.21 – Monthly whole building electricity use and average monthly outdoor dry bulb temperature comparison between the base case model with and without daylighting.

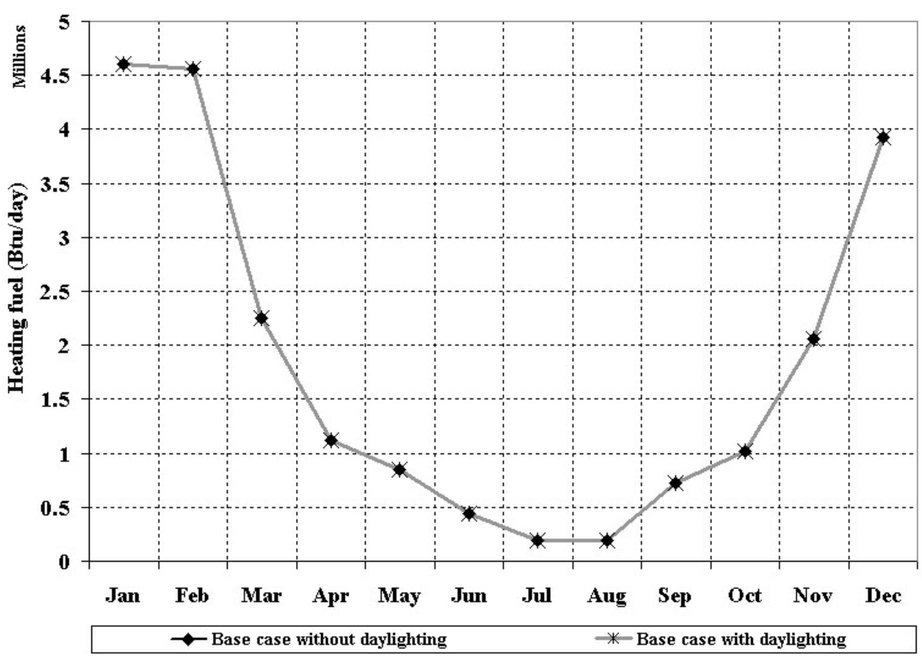


Figure 4.22 – Monthly heating fuel (natural gas) use comparison between the base case model without daylighting and base case model with daylighting.

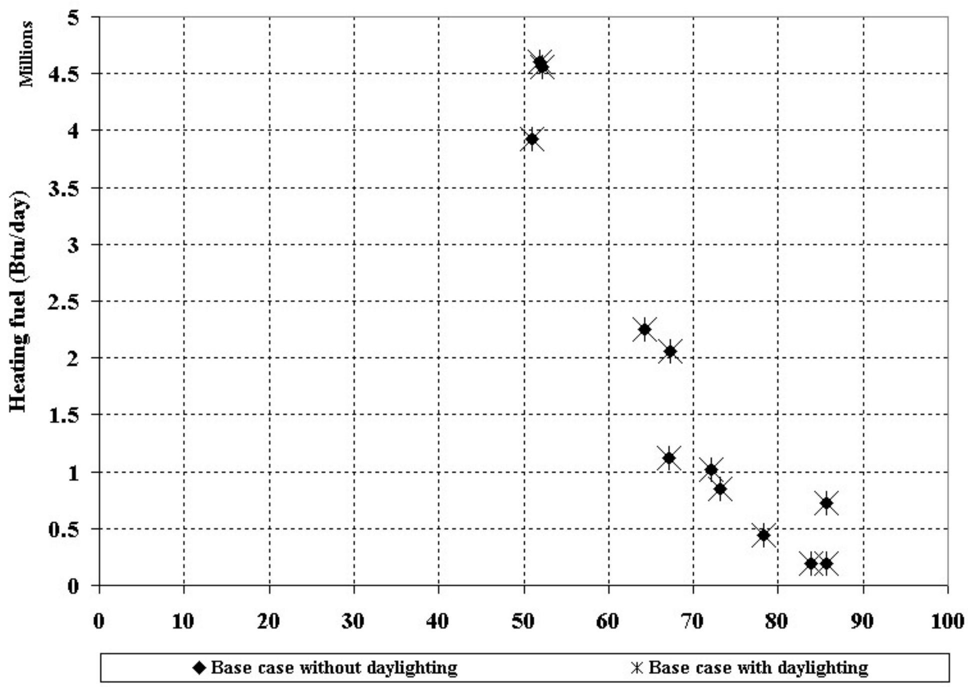


Figure 4.23 – Monthly heating fuel (natural gas) use and average monthly outdoor dry bulb temperature comparison between the base case model with and without daylighting.

Table 4.8 – Monthly electricity and natural gas use comparison between the base case model without daylighting and base case model with daylighting.

Base case without daylighting						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Electric (kWh/day)	2028.1	2231.2	1998.2	2431.1	2920.5	2683.8
Heating (Mbtu/day)	4.6	4.6	2.3	1.1	0.9	0.4
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Electric (kWh/day)	3103.0	3930.3	3177.0	2798.1	2597.0	1839.0
Heating (Mbtu/day)	0.2	0.2	0.7	1.0	2.1	3.9
Base case with daylighting						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Electric (kWh/day)	1970.2	2165.2	1941.5	2360.5	2831.5	2613.2
Heating (Mbtu/day)	4.6	4.6	2.3	1.1	0.9	0.4
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Electric (kWh/day)	3018.2	3778.7	3075.6	2711.0	2516.4	1793.9
Heating (Mbtu/day)	0.2	0.2	0.7	1.0	2.1	3.9

4.3.2. Energy Use Comparison between Base Case and Proposed Cases

The calibrated base case DOE-2 model with daylighting was used as the 'base case' for further comparison between the different proposed daylighting strategies, namely skylights and clerestories. The energy use of every model was compared with the base case energy use for the categories of monthly lighting electricity usage, monthly cooling electricity usage, whole building electricity usage, and natural gas usage for the whole year.

4.3.2.1. Base Case and Skylights Comparison

Figures 4.24 -4.27 show the comparison between the base case and the different skylight cases for the categories stated earlier.

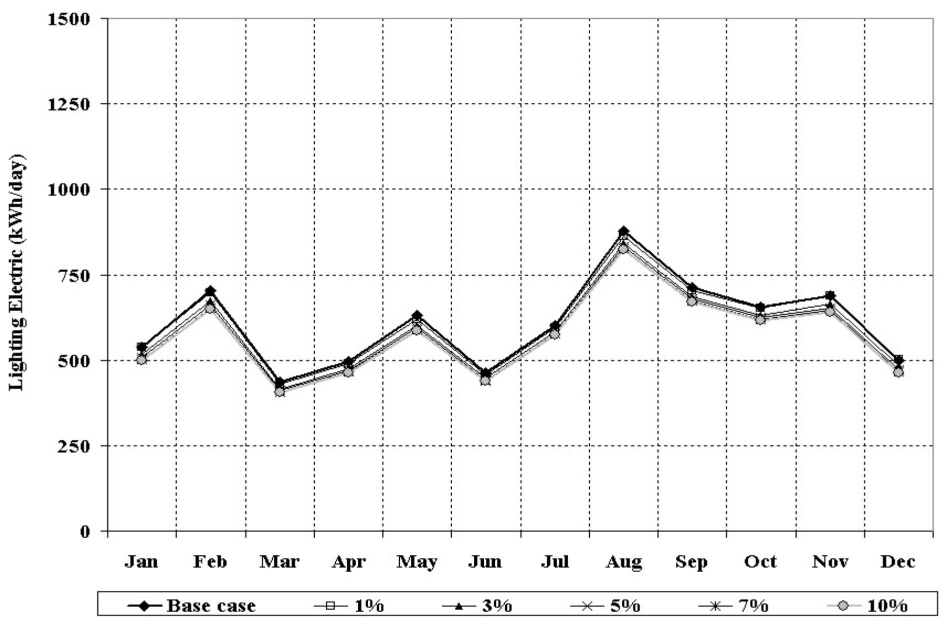


Figure 4.24 – Monthly lighting electricity use comparison between the base case and the proposed skylight cases.

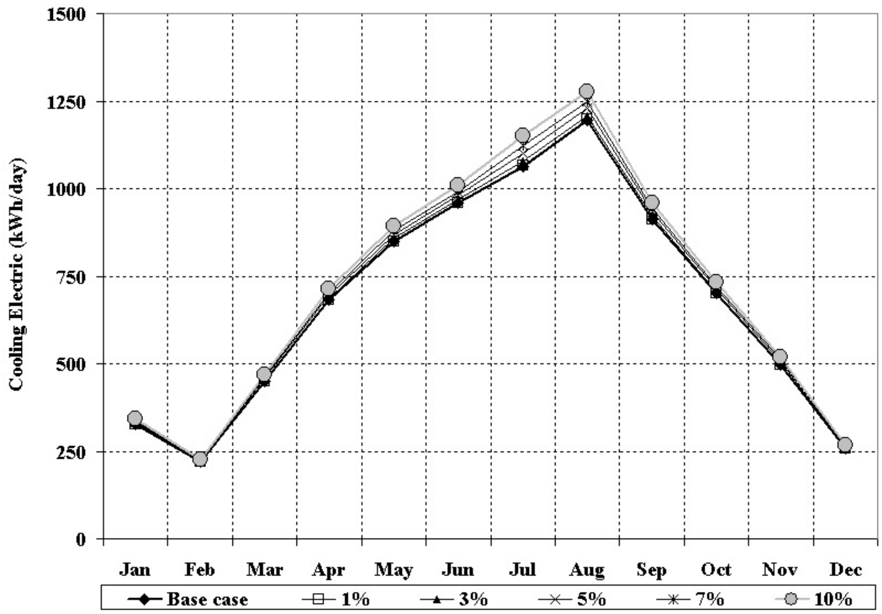


Figure 4.25 – Monthly cooling electricity use comparison between the base case and the proposed skylight cases.

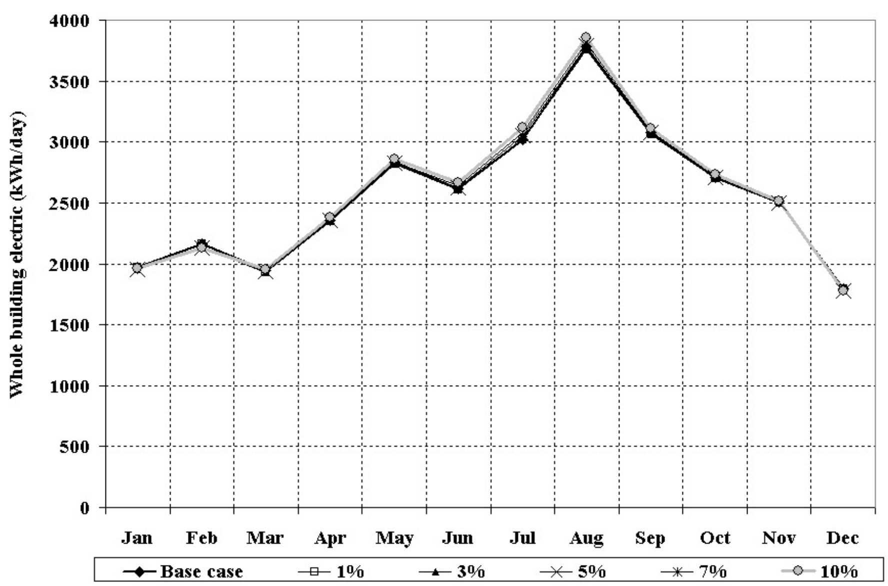


Figure 4.26 – Monthly whole building electricity use comparison between the base case and the proposed skylight cases.

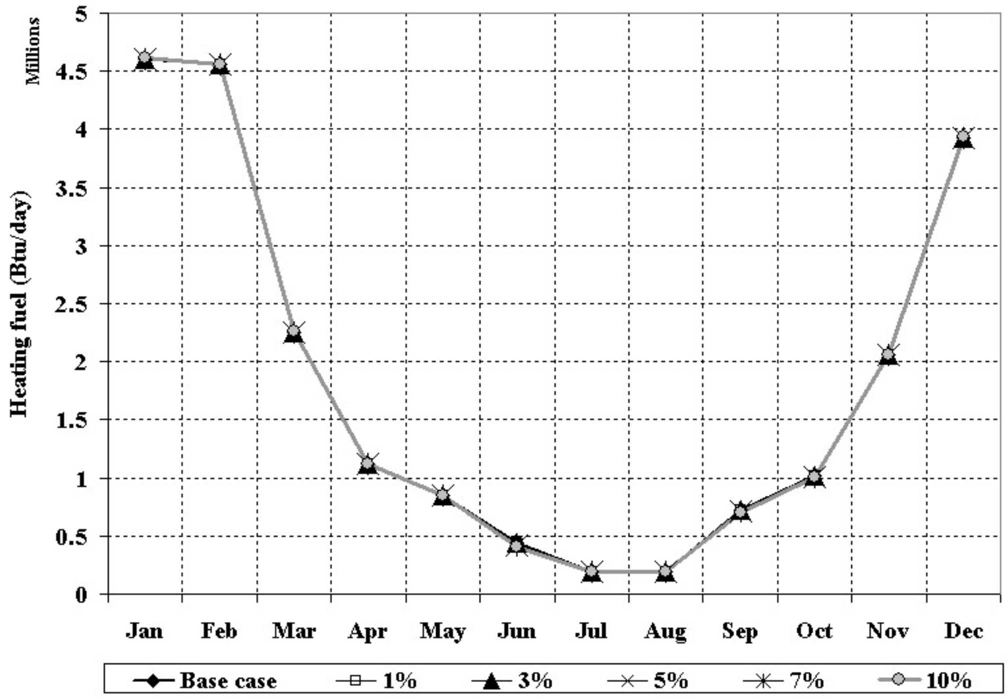


Figure 4.27 – Monthly heating fuel (natural gas) use comparison between the base case and the proposed skylight cases.

4.3.2.2. Base Case and Clerestories Comparison

Figures 4.28 -4.31 show the comparison between the base case and the different clerestories cases for the categories of monthly lighting electricity usage, monthly cooling electricity usage, whole building electricity usage, and natural gas usage for the whole year.

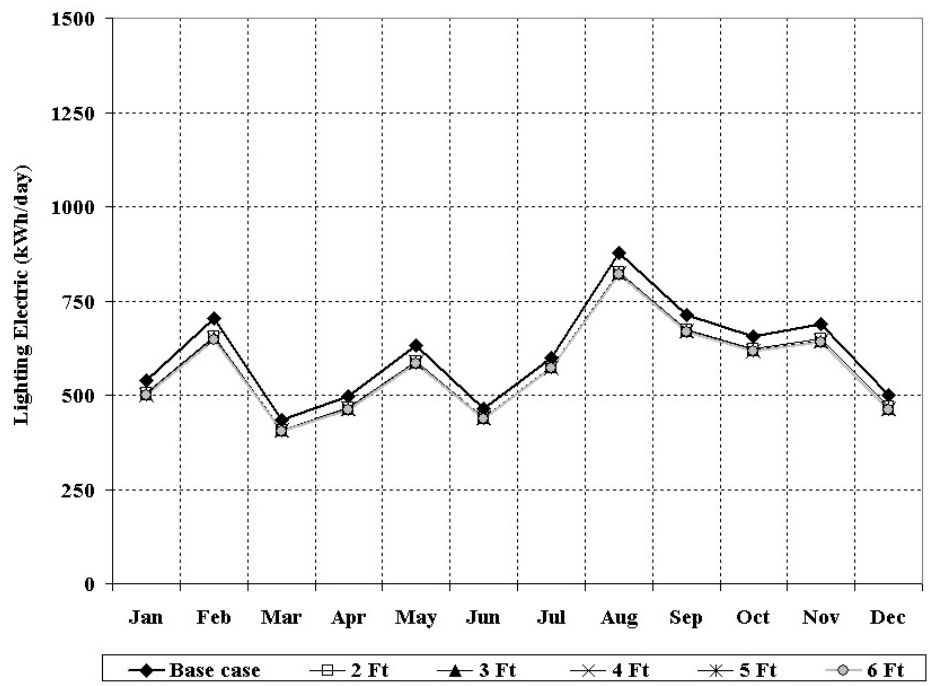


Figure 4.28 – Monthly lighting electricity use comparison between the base case and the proposed clerestory cases.

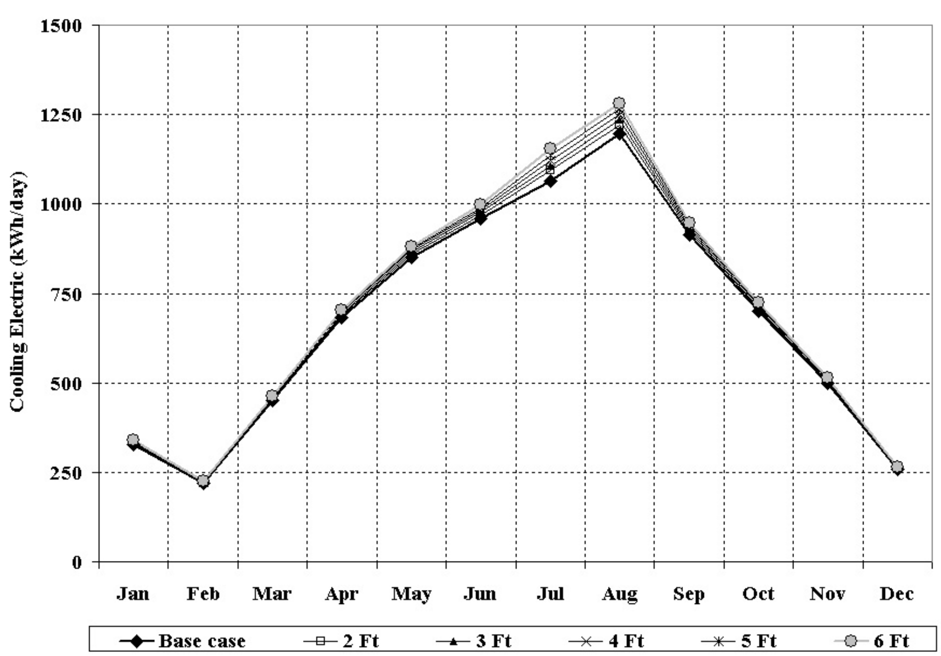


Figure 4.29 – Monthly cooling electricity use comparison between the base case and the proposed clerestory cases.

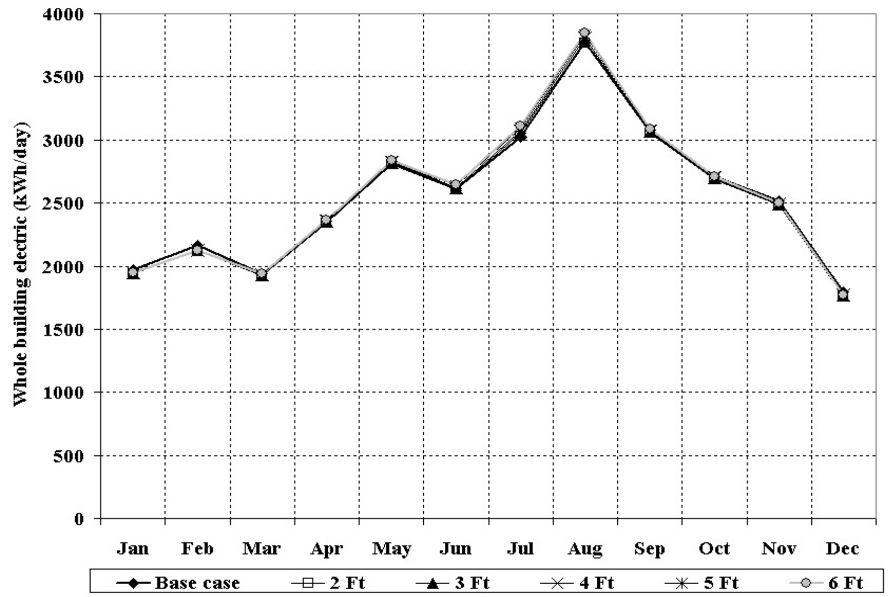


Figure 4.30 – Monthly whole building electricity use comparison between the base case and the proposed clerestory cases.

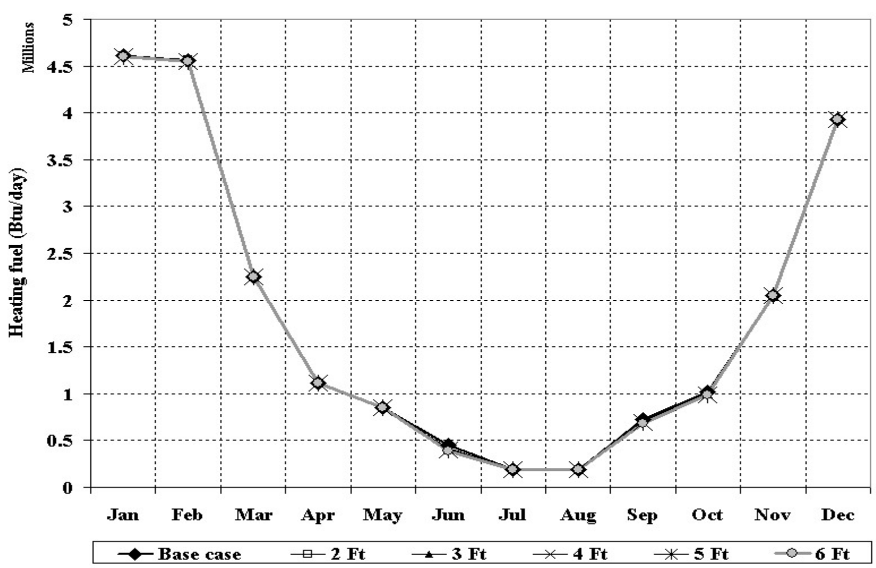


Figure 4.31 – Monthly heating fuel (natural gas) use comparison between the base case and the proposed clerestory cases.

4.3.3. Lighting Energy Analysis

One would expect lighting energy consumption to decrease when a daylighting strategy is implemented. The simulations predict that lighting energy is reduced as a result of daylighting, thus playing an important part in reducing the total electrical energy consumption. To better understand the reduction in lighting energy, the different daylighting cases (skylights and clerestories) were analyzed for March 21, June 21, September 21, and December 21 (vernal equinox, summer solstice, autumnal equinox, and winter solstice). The four days studied are representative (typical) of the four seasons of the year. The results are from the DOE-2 simulation program's 'Hourly-Report' with Variable-List number 1 (LITEKW) in PLANT.

4.3.3.1. Skylight Cases Daylighting Analysis

Figures 4.32 – 4.36 present the lighting electric consumption analysis on the four abovementioned days for the 1%, 5%, and 10% skylight cases. These three cases were selected to represent the designs with the smallest, middle, and largest skylight to roof area ratios used in this study. The lighting electric energy consumption was seen to be consistently lower than the base case in all the cases for all the four typical days. It was found to be more than 10% lower than the base case value, with a maximum of 16.5% reduction for the 10% skylight case, and a minimum of 11.5% for the 1% skylight value. The most savings were observed to occur on March 21. This might be because March 21 represented the clearest day amongst the four typical days and hence had the best potential for lighting savings through daylighting.

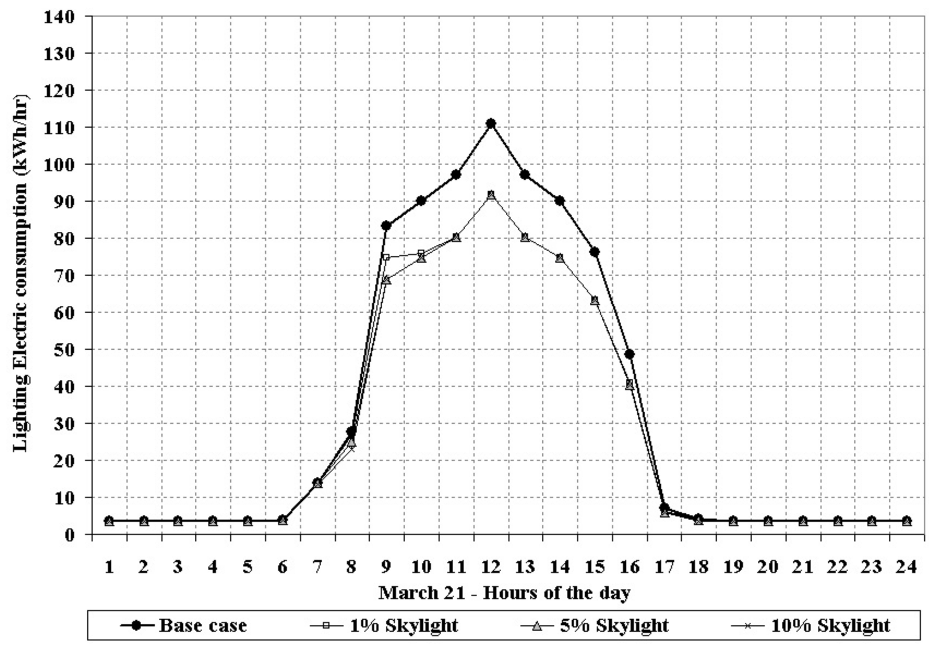


Figure 4.32 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed skylight cases on March 21.

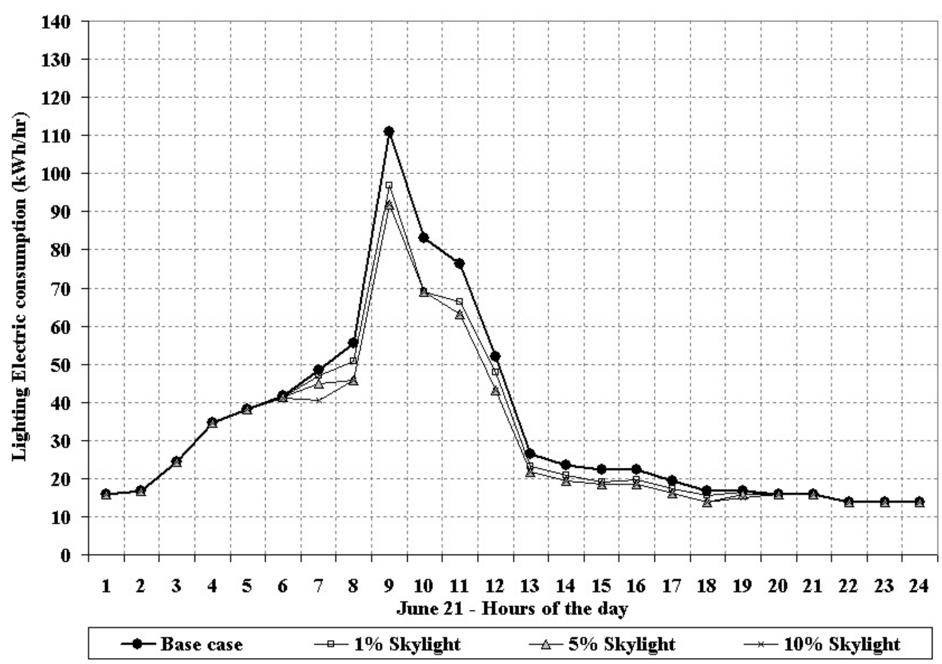


Figure 4.33 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed skylight cases on June 21.

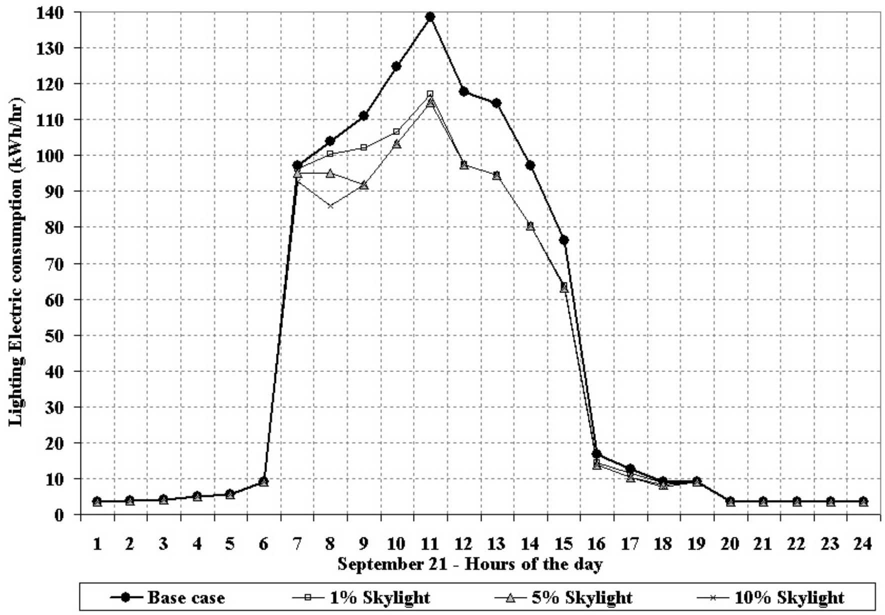


Figure 4.34 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed skylight cases on September 21.

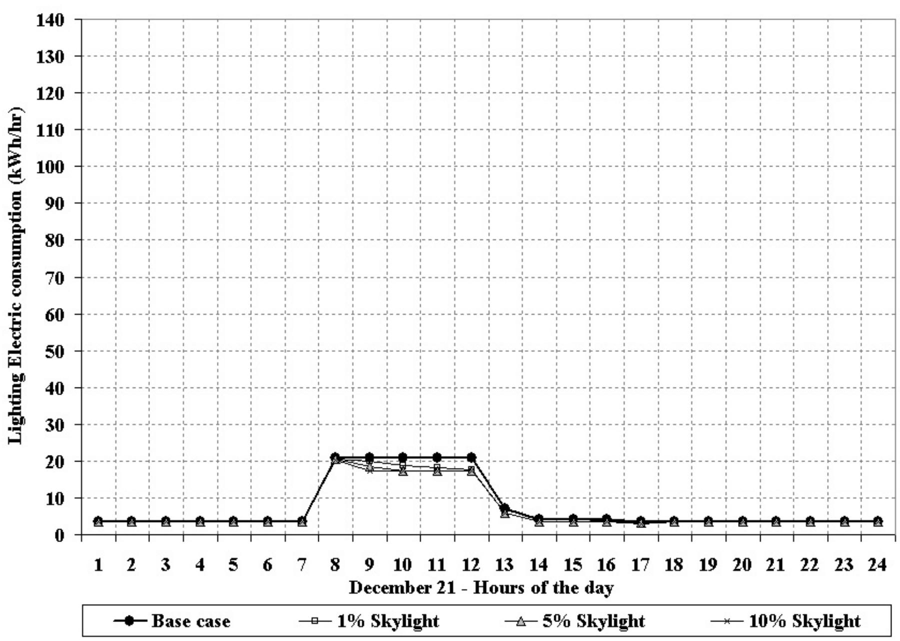


Figure 4.35 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed skylight cases on December 21.

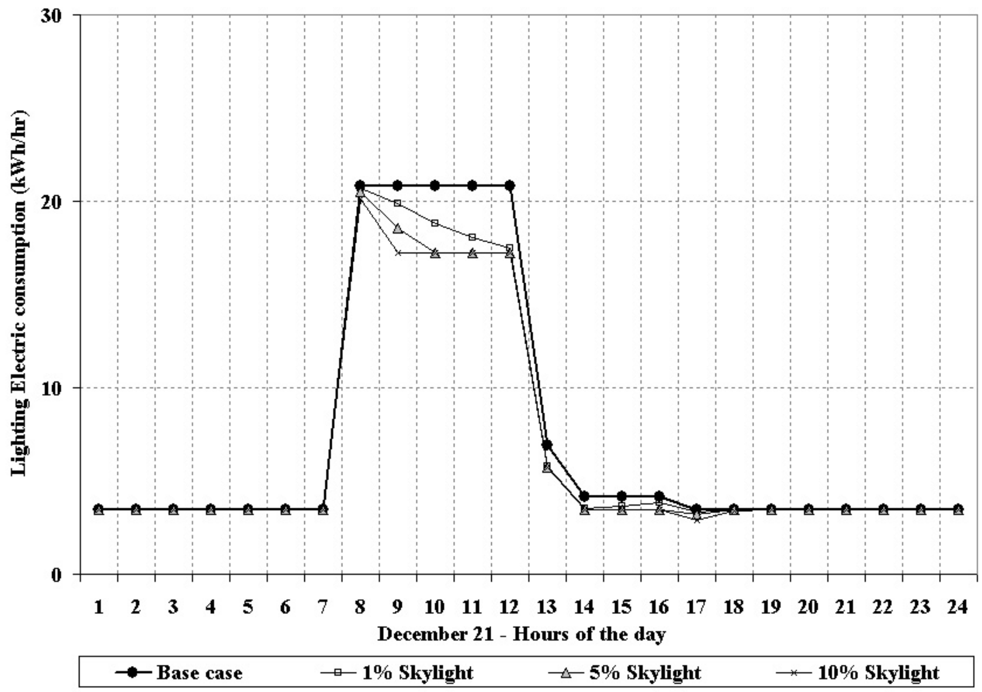


Figure 4.36 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed skylight cases on December 21. (This graph is similar in value to the graph shown in Figure 4.35 but it has been scaled to indicate the exact hourly trend in lighting electricity use on the specified day).

4.3.3.2. Clerestory Cases Daylighting Analysis

The three cases selected for clerestory analyses were the 2 ft, 4 ft, and 6 ft glazing cases to represent the designs with smallest, middle, and highest clerestory used in this study. In the case of clerestories too, the lighting electric energy consumption was seen to be consistently lower than the base case in all the cases for all four typical days. It was found to be more than 14% lower than the base case value, with a maximum of 16% reduction for the 6 ft case, and a minimum of 14.9% for the 2 ft case. The most savings were observed to be on the day of September 21, followed by March 21. Figures

4.37 – 4.41 present the lighting electric consumption analysis on the four typical days for the selected clerestory cases.

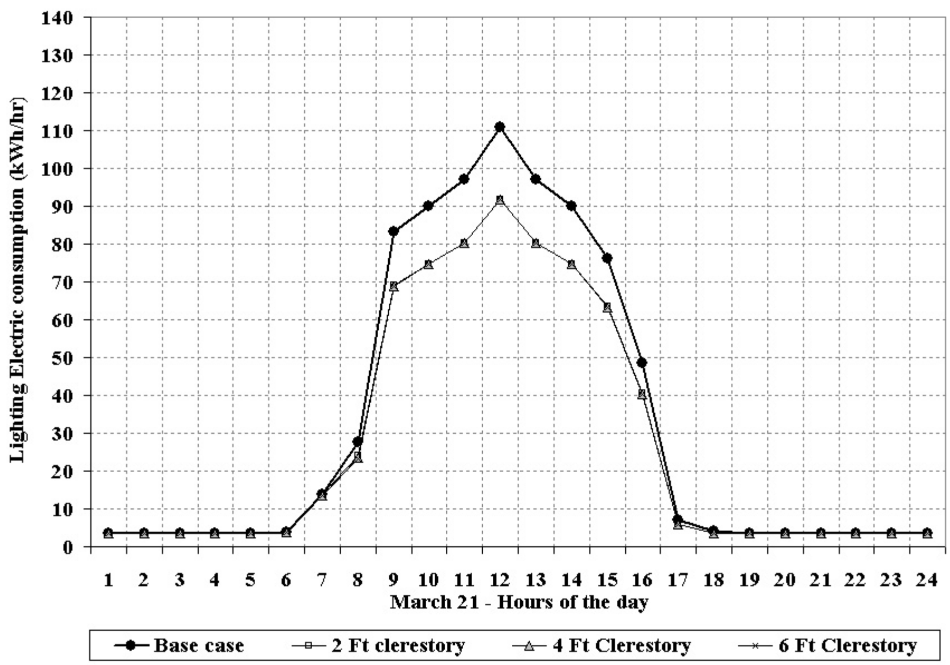


Figure 4.37 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed clerestory cases on March 21.

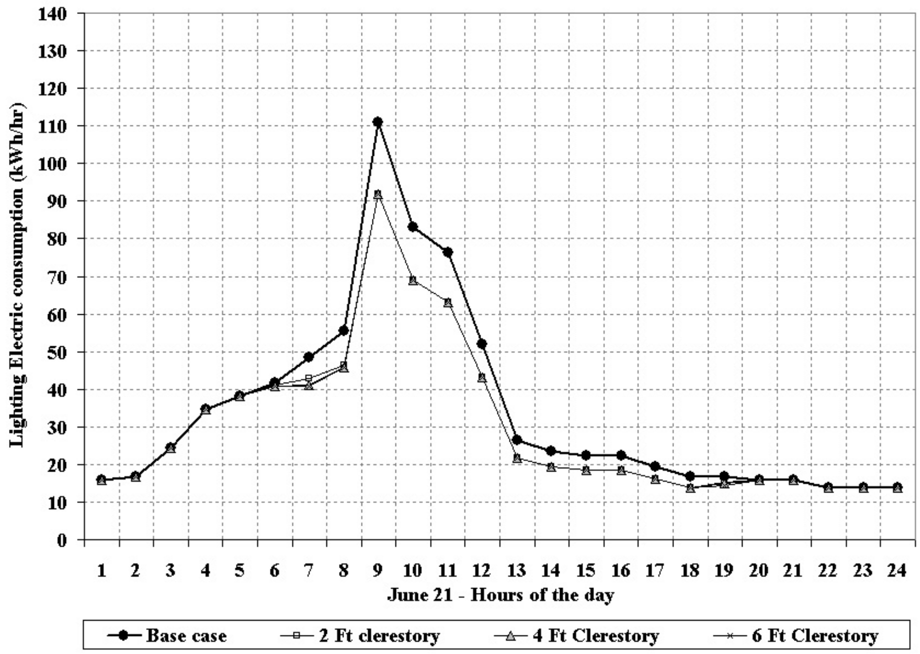


Figure 4.38 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed clerestory cases on June 21.

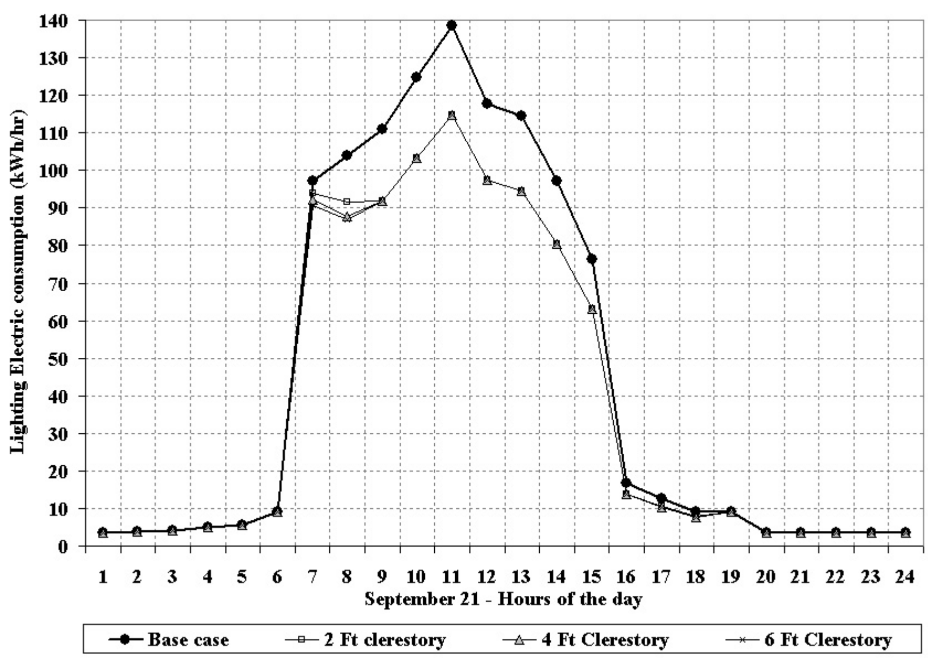


Figure 4.39 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed clerestory cases on September 21.

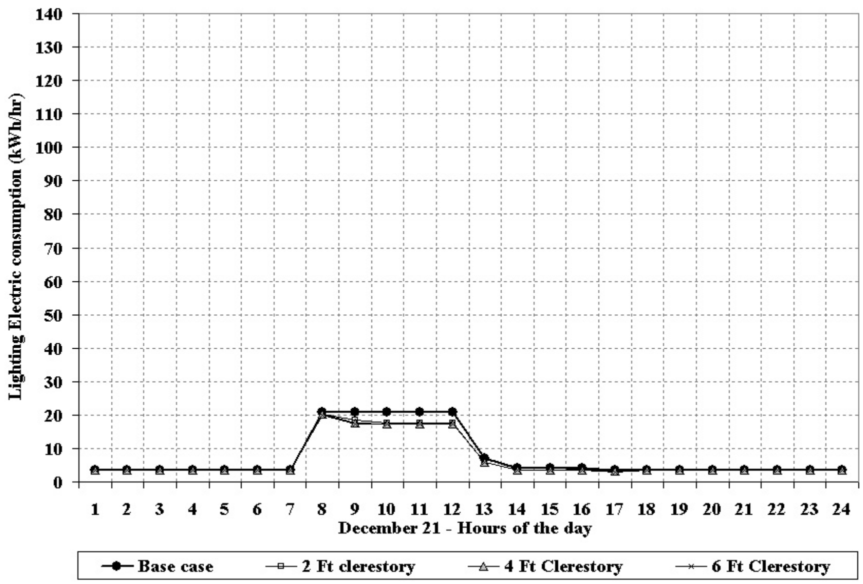


Figure 4.40 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed clerestory cases on December 21.

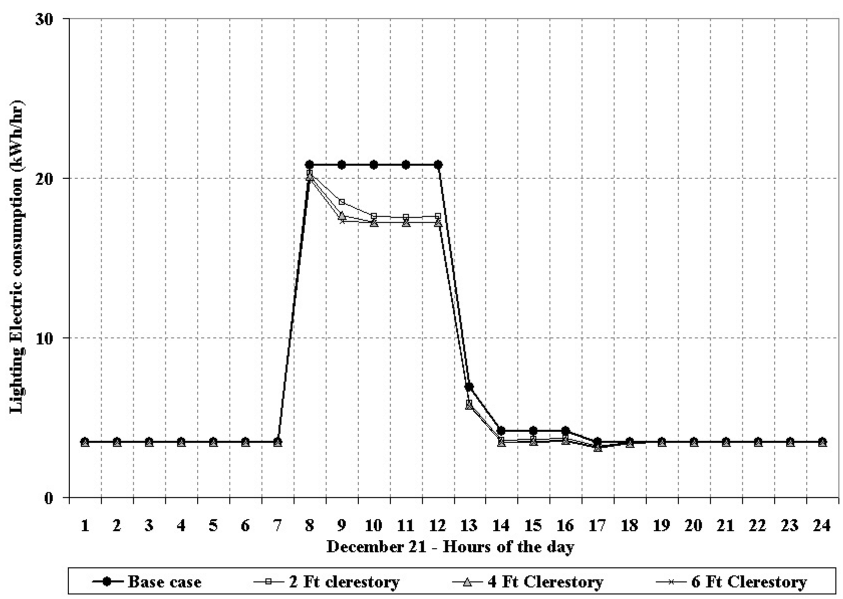


Figure 4.41 – Hourly lighting electricity use comparison between the base case model with daylighting and the proposed clerestory cases on December 21. (This graph is similar in value to the graph shown in Figure 4.40 but it has been scaled to indicate the exact hourly trend in lighting electricity use on the specified day).

The lighting energy analysis for the proposed daylighting cases showed that daylighting had effected reductions in all the four seasons of the year.

4.3.4. Cooling and Heating Energy Analysis

4.3.4.1. Outdoor Temperatures from DOE-2

Daylighting can affect cooling and heating energy consumption by reducing waste heat from lamps. Figure 4.42 shows a comparison between the outdoor dry bulb temperatures for the four typical days of March 21, June 21, September 21, and December 21. It was seen that September 21 was the hottest day amongst the four, with an average outdoor dry bulb temperature of 81 deg. F, while December 21 was the coldest day with an average outdoor dry bulb temperature of 47.5 deg. F. Hence, September 21 was selected for the cooling energy analysis, while December 21 was selected for the heating energy analysis.

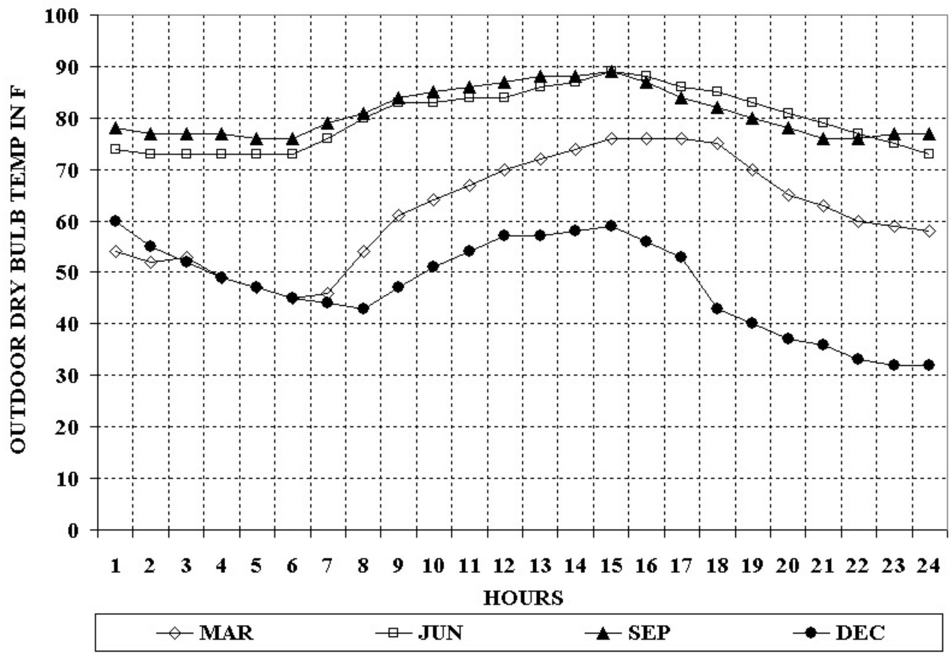


Figure 4.42 – Outdoor dry bulb temperature comparison between the days March 21, June 21, September 21, and December 21.

4.3.4.2. Cooling Energy Analysis on September 21

Figure 4.43 compares the hourly cooling electric consumption in the base case with and without daylighting, while Figures 4.44 -4.45 present the comparison between the base case and the different proposed daylighting cases (skylights and clerestories). It was seen that, although the cooling energy shows a clear decrease between the base cases, there is a consistent increase in the cooling energy between the base case and the different skylight and clerestory cases. This effect is due to the heat conduction through the glazing materials of the skylights and clerestories, which have higher u-values than opaque building materials. In the case of clerestories, surface area and volume of the building are also increased, which lead to increased energy conductance. Since there is no added glazing material in the base cases comparison, there is seen a decrease in the cooling electric energy consumption.

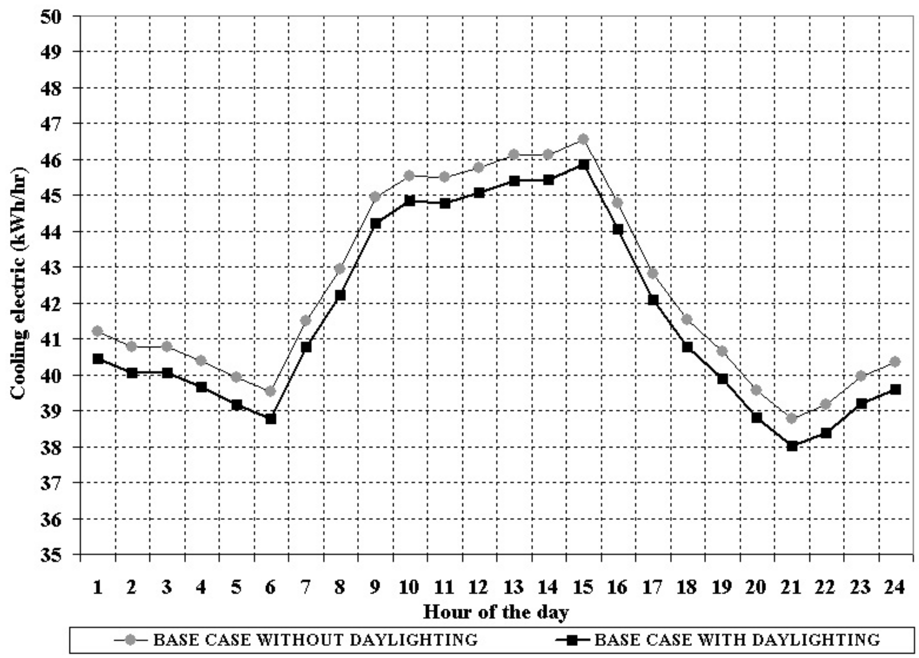


Figure 4.43 – Comparison of the hourly cooling electricity use between the base case with and without daylighting.

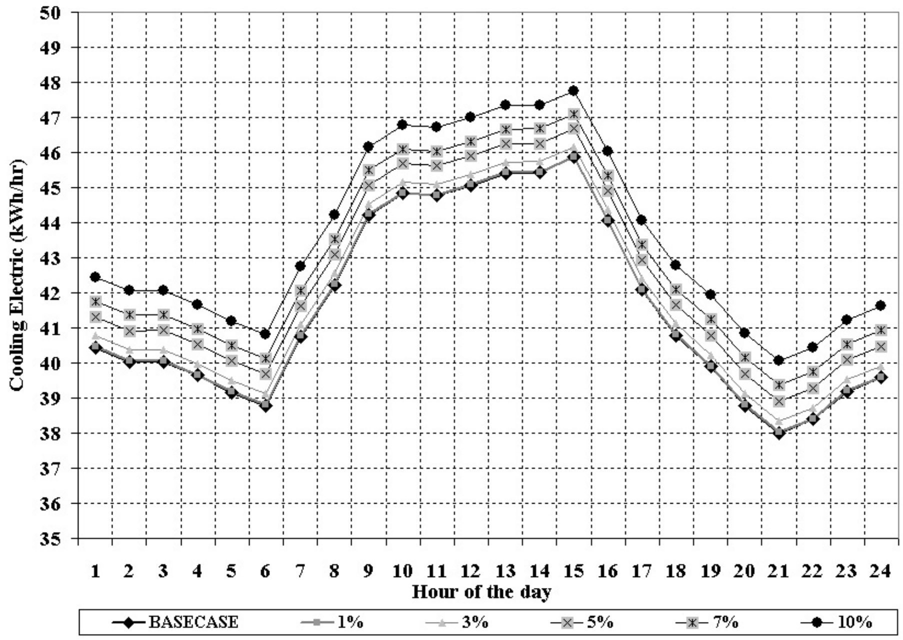


Figure 4.44 – Comparison of the hourly cooling electricity use between the base case and the different skylight cases.

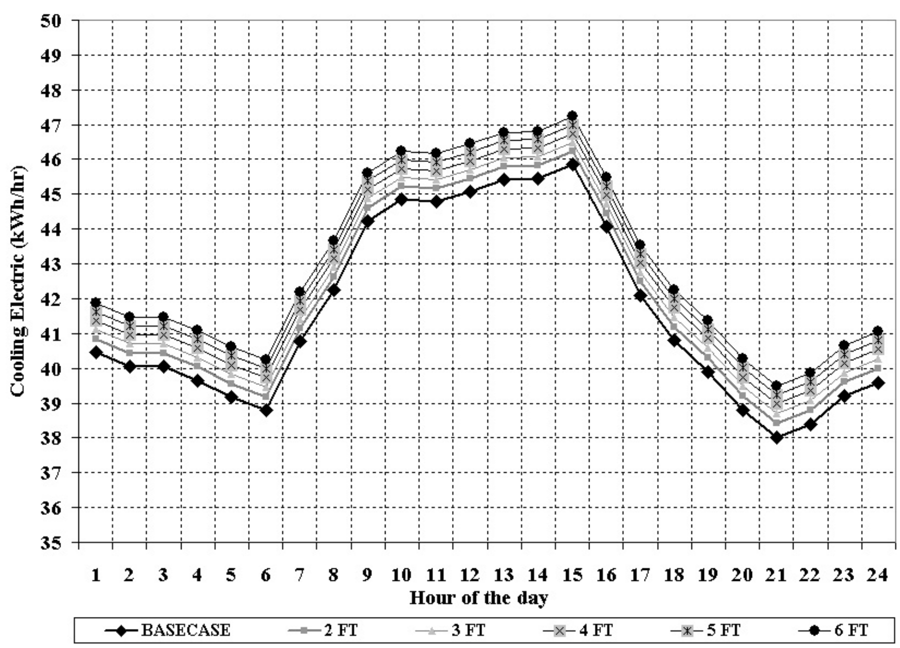


Figure 4.45 – Comparison of the hourly cooling electricity use between the base case and the different clerestory cases.

As seen from the plots above, the cooling electric use increased with increasing skylight to roof ratio and higher clerestory glazing size. The 10% skylight case was the worst among the skylight cases with a 3.43% increase in cooling energy as compared to the daylit base case.

4.3.4.3. Heating Energy Analysis on December 21

Figure 4.46 presents the comparison between the hourly heating fuel (natural gas) consumption in the base case with and without daylighting, while Figures 4.47 - 4.48 present the comparison between the base case and the different proposed daylighting cases (skylights and clerestories). No trend (increase or decrease) was observed in any of the cases. The heating energy was constant for all cases studied.

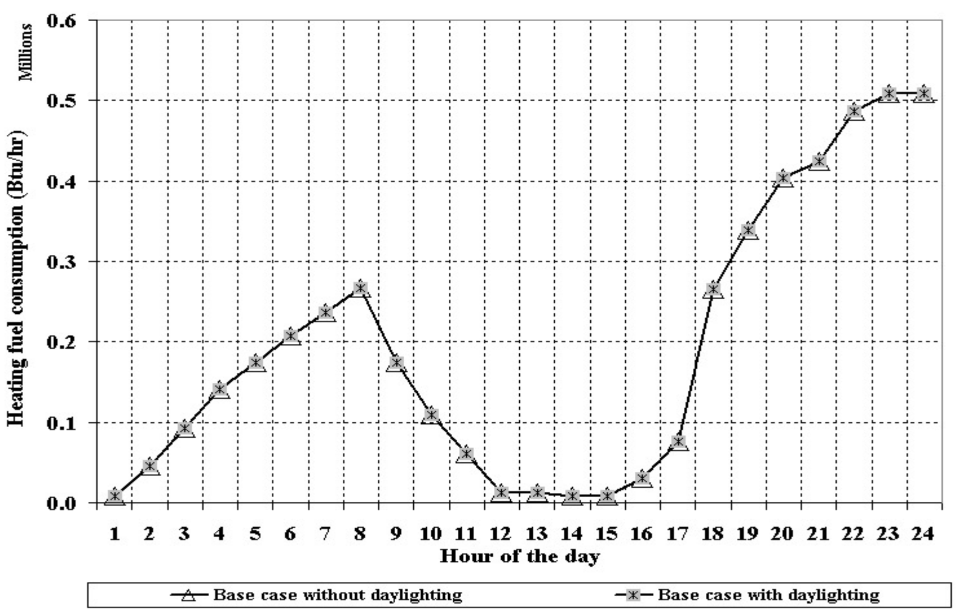


Figure 4.46 – Comparison of the hourly heating fuel (natural gas) use between the base case with and without daylighting.

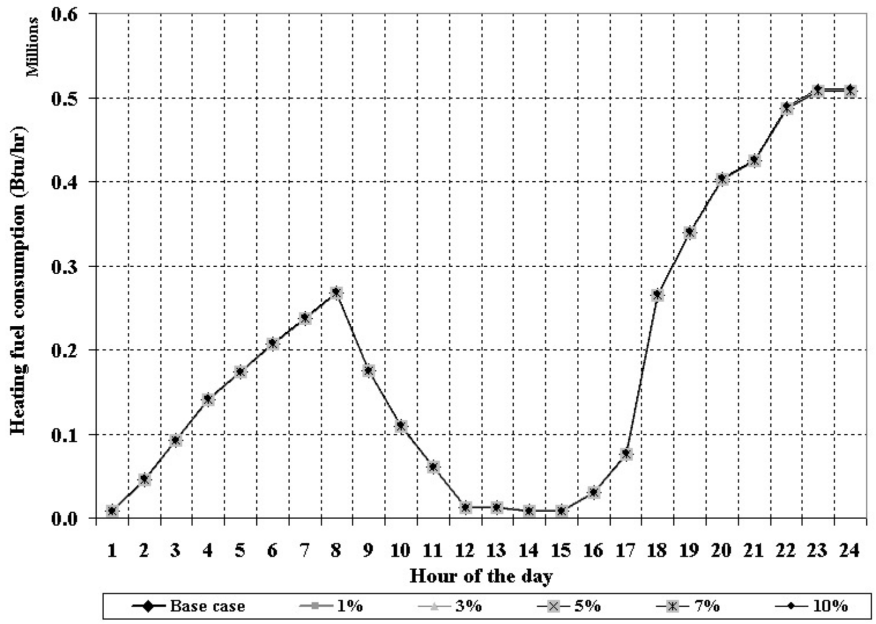


Figure 4.47 – Comparison of the hourly heating fuel (natural gas) use between the base case and the different skylight cases.

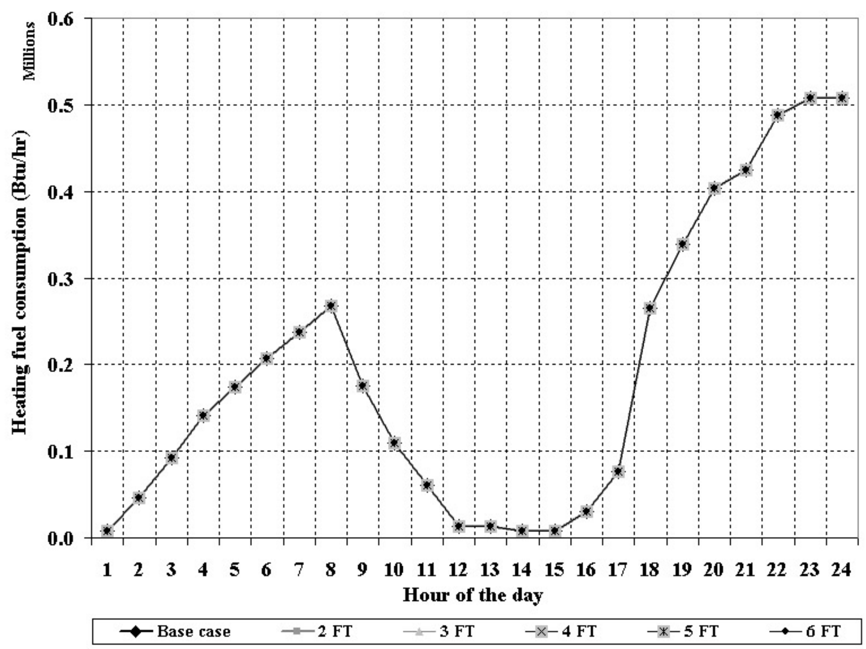


Figure 4.48 – Comparison of the hourly heating fuel (natural gas) use between the base case and the different clerestory cases.

4.3.5. Energy Analysis between Skylights and Clerestories

This section summarizes the total energy by category use for the skylight and clerestory cases as compared with the base daylighting case. Tables 4.9-4.10 present the energy use categories for the proposed cases and their respective difference (positive or negative) in comparison to the base case. The energy use is classified under the categories of area lighting, miscellaneous equipment, space heating, space cooling, heat rejection, and pumps and miscellaneous, in accordance with the 'Building Energy Performance Summary' report from the DOE-2 output.

Table 4.9 – Energy end-uses for the different skylight cases as compared to the base case.

SKYLIGHTS							
Category	**Base**	**1%**	**Diff (%)**	**3%**	**Diff (%)**	**5%**	**Diff (%)**
Area lights	828.4	750.7	9.38	727.5	12.18	718.6	13.25
Misc Equipment	781.6	781.6	0.00	781.6	0.00	781.6	0.00
Space Heating	29.9	29.9	0.00	29.9	0.00	29.8	0.33
Space Cooling	862.7	846.6	1.87	853.4	1.08	866.3	-0.42
Heat Rejection	302.9	294.8	2.67	298.2	1.55	304.5	-0.53
Pumps, Misc	113.4	110.8	2.29	111.9	1.32	113.9	-0.44
Vent Fans	379	378.2	0.21	378.4	0.16	378.9	0.03
TOTAL	**3297.90**	**3192.60**	**16.42**	**3180.90**	**16.29**	3193.5	**12.23**

Category	**Base**	**7%**	**Diff (%)**	**10%**	**Diff (%)**
Area lights	828.4	711.8	14.08	708.1	14.52
Misc Equipment	781.6	781.6	0.00	781.6	0.00
Space Heating	29.9	29.8	0.33	29.8	0.33
Space Cooling	862.7	876.8	-1.63	892.9	-3.50
Heat Rejection	302.9	309.5	-2.18	316.8	-4.59
Pumps, Misc	113.4	115.4	-1.76	117.7	-3.79
Vent Fans	379	379.4	-0.11	381	-0.53
TOTAL	**3297.90**	**3204.30**	**8.73**	**3227.90**	**2.45**

Table 4.10 – Energy end-uses for the different clerestory cases as compared to the base case.

CLERESTORIES							
Category	**Base**	**2**	**Diff (%)**	**3**	**Diff (%)**	**4**	**Diff (%)**
Area lights	828.4	714.4	13.76	710.6	14.22	708.6	14.46
Misc Equipment	781.6	781.6	0.00	781.6	0.00	781.6	0.00
Space Heating	29.9	29.8	0.33	29.8	0.33	29.7	0.67
Space Cooling	862.7	857.3	0.63	864.4	-0.20	871.4	-1.01
Heat Rejection	302.9	299.2	1.22	302.2	0.23	305.3	-0.79
Pumps and Misc	113.4	112.2	1.06	113.1	0.26	114.1	-0.62
Vent Fans	379	378.9	0.03	379.3	-0.08	379.8	-0.21
TOTAL	**3297.90**	**3173.40**	**17.03**	**3181.00**	**14.77**	**3190.50**	**12.50**

Category	**Base**	**5**	**Diff (%)**	**6**	**Diff (%)**
Area lights	828.4	707.4	14.61	706.6	14.70
Misc Equipment	781.6	781.6	0.00	781.6	0.00
Space Heating	29.9	29.7	0.67	29.6	1.00
Space Cooling	862.7	878.4	-1.82	885.3	-2.62
Heat Rejection	302.9	308.2	-1.75	311.1	-2.71
Pumps and Misc	113.4	115	-1.41	115.9	-2.20
Vent Fans	379	380.3	-0.34	380.8	-0.47
TOTAL	**3297.90**	**3200.60**	**9.95**	**3210.90**	**7.70**

Figures 4.49 -4.50 display the trends observed in the various energy end-uses for the skylight and clerestory cases. ‘Space cooling’ shows a consistent increase in both categories, while ‘Area lights’ indicates a consistent decrease in the skylight cases whereas in the clerestory cases, it decreases rapidly from the base case, but then remains almost constant for all the other cases (2 ft to 6 ft).

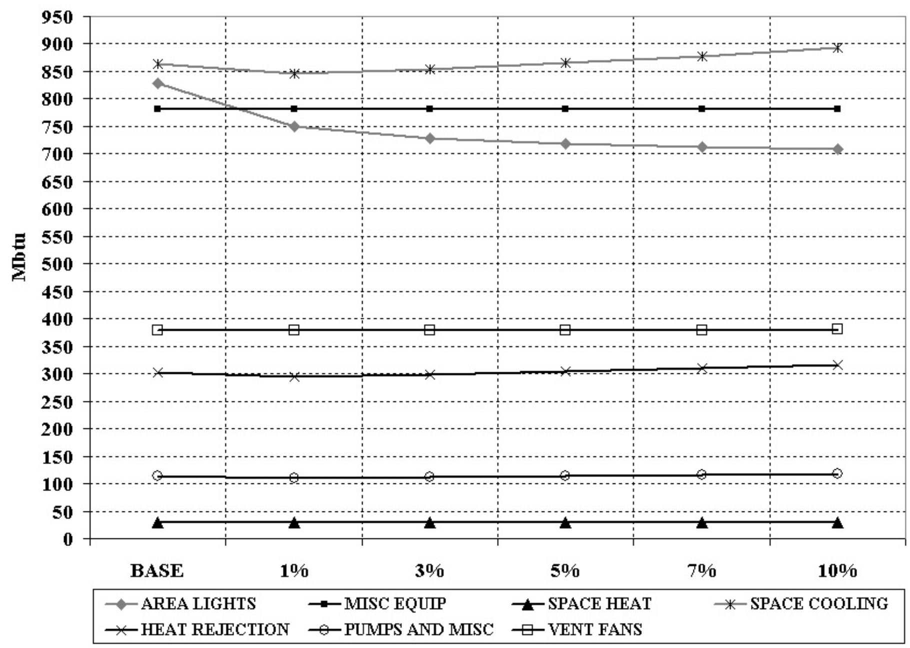


Figure 4.49 – Trends observed in the various energy end-uses for the skylight cases as compared with the base case.

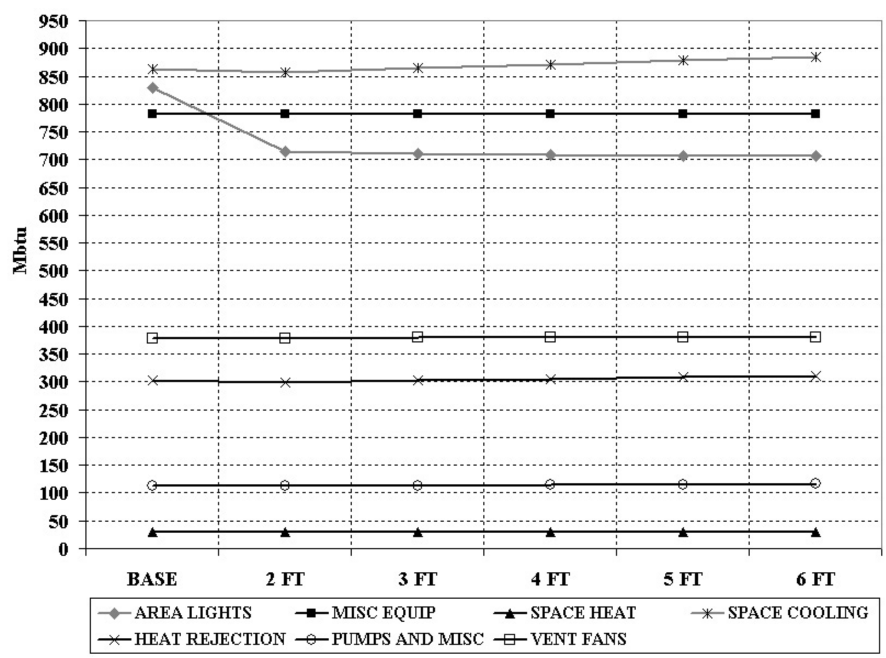
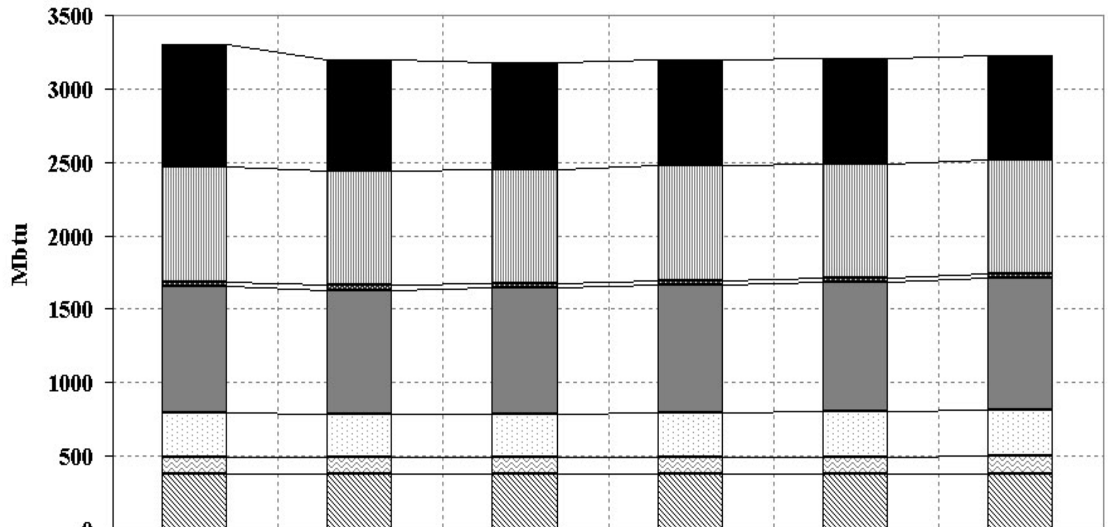


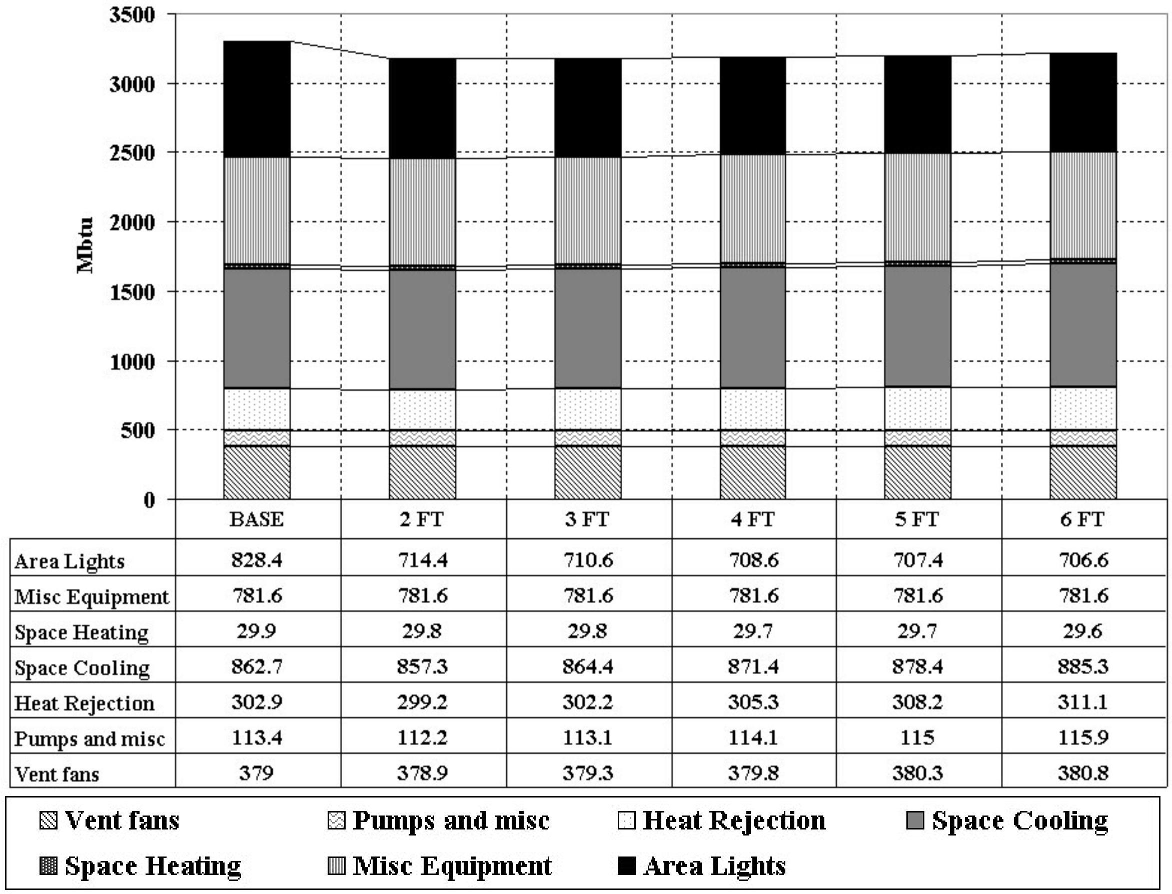
Figure 4.50 – Trends observed in the various energy end-uses for the clerestory cases as compared with the base case.

Figures 4.51 –4.52 show the energy end-use comparisons between the base case and the proposed cases. This information is the same as presented earlier in this section in Tables 4.9-4.10.



	BASE	1%	3%	5%	7%	10%
Area Lights	828.4	750.7	727.5	718.6	711.8	708.1
Misc Equipment	781.6	781.6	781.6	781.6	781.6	781.6
Space Heating	29.9	29.9	29.9	29.8	29.8	29.8
Space Cooling	862.7	846.6	853.4	866.3	876.8	892.9
Heat Rejection	302.9	294.8	298.2	304.5	309.5	316.8
Pumps and misc	113.4	110.8	111.9	113.9	115.4	117.7
Vent fans	379	378.2	378.4	378.9	379.4	381

Figure 4.51 –Energy end-uses for the skylight cases as compared with the base case.



	BASE	2 FT	3 FT	4 FT	5 FT	6 FT
Area Lights	828.4	714.4	710.6	708.6	707.4	706.6
Misc Equipment	781.6	781.6	781.6	781.6	781.6	781.6
Space Heating	29.9	29.8	29.8	29.7	29.7	29.6
Space Cooling	862.7	857.3	864.4	871.4	878.4	885.3
Heat Rejection	302.9	299.2	302.2	305.3	308.2	311.1
Pumps and misc	113.4	112.2	113.1	114.1	115	115.9
Vent fans	379	378.9	379.3	379.8	380.3	380.8

Figure 4.52 –Energy end-uses for the clerestory cases as compared with the base case.

4.4. ECONOMICS

4.4.1. Energy Savings Due to Proposed Designs

A recommendation regarding which design is best can rationally be based on the actual energy and energy cost savings due to each variant. Tables 4.11 and 4.12 represent the cooling energy, lighting energy, electricity, and natural gas savings, while Table 4.13 shows the total energy savings for all the proposed cases.

The 1% and 3% skylight cases and the 2 ft clerestory case were the 3 cases that provided some cooling energy savings. All other cases showed increased energy costs due to cooling. Lighting energy savings were the highest at 14.70% for the 6 ft clerestory glazing, followed closely by the 10% skylight case at 14.52%. These two cases performed the worst though in terms of cooling energy saving. Clerestory cases performed better than skylight cases in terms of heating energy (natural gas use) savings, with all clerestory cases showing positive, though minimal savings. Total electricity use was best in the 3% skylight case and the 2 ft clerestory case. The 2 ft glazing case performed slightly better than the skylight case.

Table 4.11 –Energy savings due to the proposed skylight cases. Energy savings are classified into cooling, lighting, electricity, and natural gas use savings.

Skylights	**Cooling (Mbtu)**	**Savings (Mbtu)**	**Savings (%)**	**Lighting (Mbtu)**	**Savings (Mbtu)**	**Savings (%)**
Base case	862.70			828.40		
1% Skylight	846.60	16.10	**1.87**	750.70	77.70	**9.38**
3% Skylight	853.40	9.30	**1.08**	727.50	100.90	**12.18**
5% Skylight	866.30	-3.60	**-0.42**	718.60	109.80	**13.25**
7% Skylight	876.80	-14.10	**-1.63**	711.80	116.60	**14.08**
10% Skylight	892.90	-30.20	**-3.50**	708.10	120.30	**14.52**

Skylights	**Electricity (Mbtu)**	**Savings (Mbtu)**	**Savings (%)**	**N. Gas (Mbtu)**	**Savings (Mbtu)**	**Savings (%)**
Base case	3297.9			661.3		
1% Skylight	3192.50	105.40	**3.20**	661.90	-0.60	**-0.09**
3% Skylight	3180.90	117.00	**3.55**	661.50	-0.20	**-0.03**
5% Skylight	3193.50	104.40	**3.17**	660.90	0.40	**0.06**
7% Skylight	3204.20	93.70	**2.84**	660.40	0.90	**0.14**
10% Skylight	3227.90	70.00	**2.12**	661.40	-0.10	**-0.02**

Table 4.12 –Energy savings due to the proposed clerestory cases. Energy savings are classified into cooling, lighting, electricity, and natural gas use savings.

Clerestory	Cooling (Mbtu)	Savings (Mbtu)	Savings (%)	Lighting (Mbtu)	Savings (Mbtu)	Savings (%)
Base case	862.7			828.4		
2 ft glazing	857.3	5.40	**0.63**	714.4	114.00	**13.76**
3 ft glazing	864.4	-1.70	**-0.20**	710.6	117.80	**14.22**
4 ft glazing	871.4	-8.70	**-1.01**	708.6	119.80	**14.46**
5 ft glazing	878.4	-15.70	**-1.82**	707.4	121.00	**14.61**
6 ft glazing	885.3	-22.60	**-2.62**	706.6	121.80	**14.70**

Clerestory	Electricity (Mbtu)	Savings (Mbtu)	Savings (%)	Natural Gas (Mbtu)	Savings (Mbtu)	Savings (%)
Base case	3297.9			661.3		
2 ft glazing	3173.3	124.60	**3.78**	660.6	0.70	**0.11**
3 ft glazing	3181	116.90	**3.54**	659.9	1.40	**0.21**
4 ft glazing	3190.4	107.50	**3.26**	659.1	2.20	**0.33**
5 ft glazing	3200.5	97.40	**2.95**	658.4	2.90	**0.44**
6 ft glazing	3210.8	87.10	**2.64**	657.6	3.70	**0.56**

Table 4.13 –Total energy savings due to the proposed skylight and clerestory cases.

Skylights	Total Energy (Mbtu)	Savings (Mbtu)	Savings (%)	Performance rank (most savings=1 to least savings=5)
Base case	3959.23			
1% Skylight	3854.40	104.83	**2.648**	2
3% Skylight	**3842.40**	**116.83**	**2.951**	**Most savings (1)**
5% Skylight	3854.46	104.77	**2.646**	3
7% Skylight	3864.58	94.65	**2.391**	4
10% Skylight	3889.35	69.88	**1.765**	Least savings (5)

Table 4.13 – Continued

Clerestories	**Total Energy**	**Savings**	**Savings**	**Performance rank**
	(Mbtu)	**(Mbtu)**	**(%)**	(most savings=1 to
				least savings=5)
Base case	3959.23			
2 ft glazing	**3833.88**	**125.35**	**3.166**	**Most Savings (1)**
3 ft glazing	3840.87	118.36	**2.989**	2
4 ft glazing	3849.56	109.67	**2.770**	3
5 ft glazing	3858.87	100.36	**2.535**	4
6 ft glazing	3868.46	90.77	**2.293**	Least Savings (5)

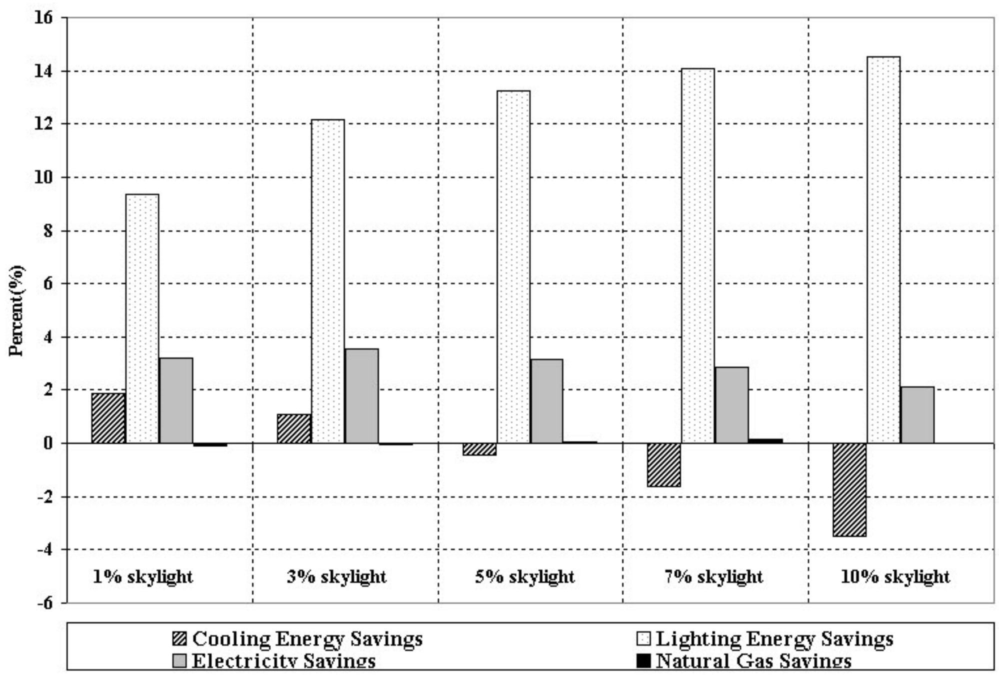


Figure 4.53 –Energy savings: skylights

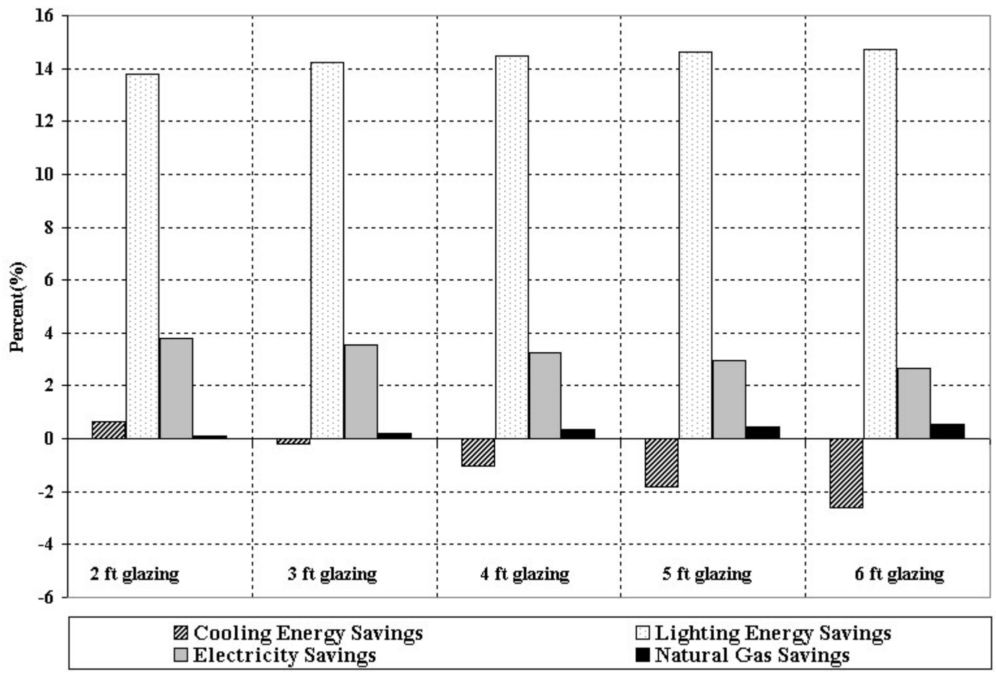


Figure 4.54 –Energy savings: clerestories

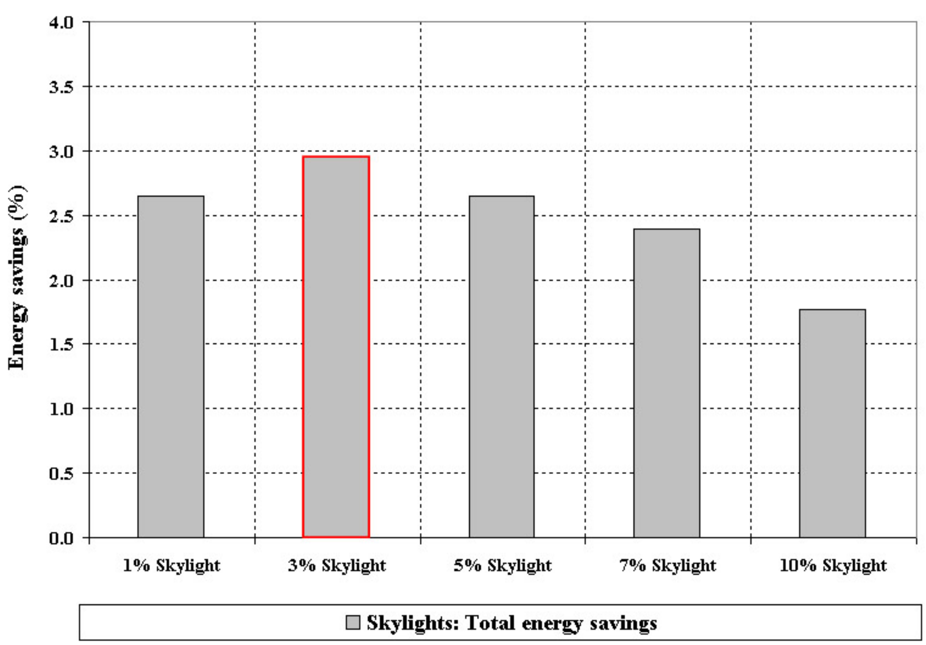


Figure 4.55 –Total energy savings for the proposed skylight cases

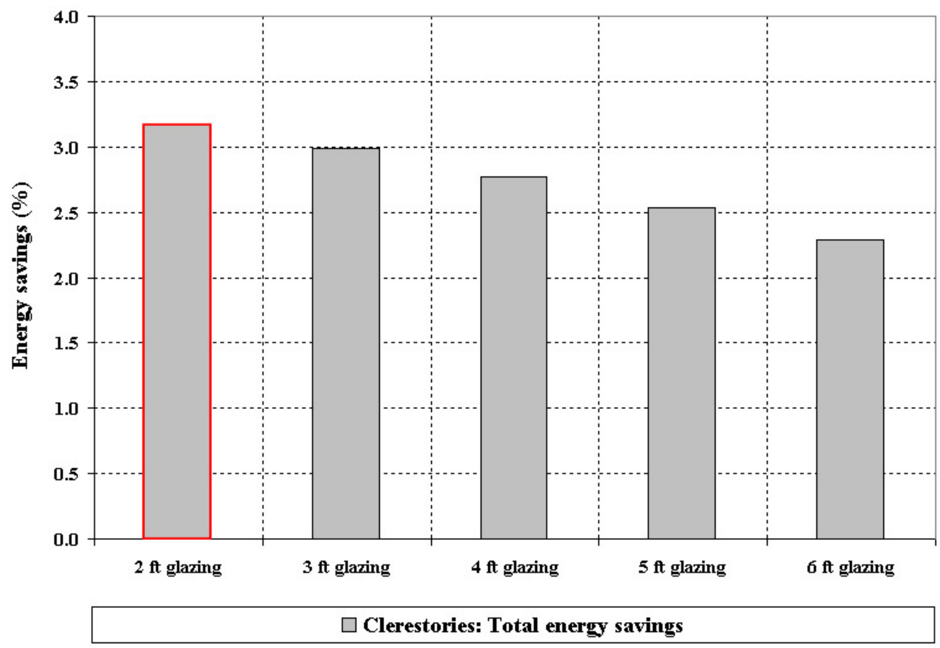


Figure 4.56 –Total energy savings for the proposed clerestory cases

Figures 4.53-4.54 show the percent energy savings for the skylights and clerestories. Table 4.13 and Figures 4.55-4.56 show the total energy savings for all the proposed skylight and clerestory cases. <u>The 3% skylight case was the best among the skylight cases, while the 2 ft glazing performed best in the clerestory category</u>. In total, all the proposed cases perform better than the base case in terms of total energy savings.

Tables 4.14 – 4.18 show the performance of all the proposed cases studied according to rank, starting with the case performing the best to the least effective case in the individual categories of cooling energy, lighting energy, electricity use, natural gas use, and total energy use. The 1% skylight case was the best in cooling energy savings while the 10% skylight case was the least effective. The 6 ft clerestory glazing case performed best in the lighting energy and natural gas use categories, while the 1% skylight case ranked last in these two categories. The 2 ft clerestory glazing performed best overall (total energy) while the 10% skylight case was the least effective.

Table 4.14 –Cooling energy comparison for all cases ranked according to performance.

Rank	Proposed case	Cooling Energy	Energy Savings
		(Mbtu)	**(in %)**
1	1% skylight area	846.6	**1.87**
2	3% skylight area	853.4	**1.08**
3	2 ft clerestory	857.3	**0.63**
4	3 ft clerestory	864.4	**-0.2**
5	5% skylight area	866.3	**-0.42**
6	4 ft clerestory	871.4	**-1.01**
7	7% skylight area	876.8	**-1.63**
8	5 ft clerestory	878.4	**-1.82**
9	6 ft clerestory	885.3	**-2.62**
10	10% skylight area	892.9	**-3.5**

Table 4.15 –Lighting energy comparison for all cases ranked according to performance.

Rank	Proposed case	Lighting Energy	Energy Savings
		(Mbtu)	**(in %)**
1	6 ft clerestory	706.6	**14.7**
2	5 ft clerestory	707.4	**14.61**
3	10% skylight area	708.1	**14.52**
4	4 ft clerestory	708.6	**14.46**
5	3 ft clerestory	710.6	**14.22**
6	7% skylight area	711.8	**14.08**
7	2 ft clerestory	714.4	**13.76**
8	5% skylight area	718.6	**13.25**
9	3% skylight area	727.5	**12.18**
10	1% skylight area	750.7	**9.38**

Table 4.16 –Electricity use comparison for all cases ranked according to performance.

Rank	Proposed case	Electricity	Energy Savings
		(Mbtu)	**(in %)**
1	2 ft clerestory	3173.3	**3.78**
2	3% skylight area	3180.9	**3.55**
3	3 ft clerestory	3181	**3.54**
4	4 ft clerestory	3190.4	**3.26**
5	1% skylight area	3192.5	**3.2**
6	5% skylight area	3193.5	**3.17**
7	5 ft clerestory	3200.5	**2.95**
8	7% skylight area	3204.2	**2.84**
9	6 ft clerestory	3210.8	**2.64**
10	10% skylight area	3227.9	**2.12**

Table 4.17 –Natural Gas use comparison for all cases ranked according to performance.

Rank	Proposed case	Natural Gas	Energy Savings
		(Mbtu)	**(in %)**
1	6 ft clerestory	657.6	**0.56**
2	5 ft clerestory	658.4	**0.44**
3	4 ft clerestory	659.1	**0.33**
4	3 ft clerestory	659.9	**0.21**
5	7% skylight area	660.4	**0.14**
6	2 ft clerestory	660.6	**0.11**
7	5% skylight area	660.9	**0.06**
8	10% skylight area	661.4	**-0.02**
9	3% skylight area	661.5	**-0.03**
10	1% skylight area	661.9	**-0.09**

Table 4.18 –Total energy use for all cases ranked according to performance.

Rank	Proposed case	Total Energy	Energy Savings
		(Mbtu)	**(in %)**
1	2 ft clerestory	3833.88	**3.17**
2	3 ft clerestory	3840.87	**2.99**
3	3% skylight area	3842.4	**2.95**
4	4 ft clerestory	3849.56	**2.77**
5	1% skylight area	3854.4	**2.65**
6	5% skylight area	3854.46	**2.65**
7	5 ft clerestory	3858.87	**2.53**
8	7% skylight area	3864.58	**2.39**
9	6 ft clerestory	3868.46	**2.29**
10	10% skylight area	3889.35	**1.76**

4.4.2. Energy Cost Savings Due to Proposed Designs

In conclusion, all the proposed cases were evaluated for their respective energy cost savings over the base case. Tables 4.19 and 4.20 show the savings achieved through cooling electric, lighting electric, total electric, and natural gas usage, and Table 4.21 shows the total annual cost savings for the proposed cases. The 3% skylight area indicates the most cost savings among all the skylight cases, while the 2 ft glazing shows most cost savings among all the clerestory cases.

The cost of electricity used for all the calculations in the following tables was considered to be \$ 0.075 per kWh consumption. The cost of natural gas used for the following calculations was considered to be \$ 0.8 per CCF consumption. This data was obtained from the official energy statistics at the Energy Information Administration website of the U.S. Department of Energy (EIA 2004).

Table 4.19 –Energy cost ($) savings due to the proposed skylight cases. Energy cost savings are classified into cooling, lighting, electricity, and natural gas use savings.

Skylights	**Cooling Elec. Use(kWh)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	252773	18958.0	
1% Skylight Area	248066	18605.0	353.02
3% Skylight Area	250053	18754.0	204.00
5% Skylight Area	253823	19036.7	-78.75
7% Skylight Area	256892	19266.9	-308.92
10% Skylight Area	261616	19621.2	-663.23
Skylights	**Total Elec. Use (kWh)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	966281	72471.1	
1% Skylight Area	935413	70156.0	2315.10
3% Skylight Area	932005	69900.4	2570.70
5% Skylight Area	935708	70178.1	2292.98
7% Skylight Area	938837	70412.8	2058.30
10% Skylight Area	945780	70933.5	1537.58

Skylights	**Lighting Elec. Use (kWh)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	242729	18204.7	
1% Skylight Area	219953	16496.5	1708.20
3% Skylight Area	213166	15987.5	2217.23
5% Skylight Area	210558	15791.9	2412.83
7% Skylight Area	208557	15641.8	2562.90
10% Skylight Area	207471	15560.3	2644.35
Skylights	**Total Natural Gas Use (CCF)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	6613	5290.4	
1% Skylight Area	6619	5295.2	-4.80
3% Skylight Area	6615	5292.0	-1.60
5% Skylight Area	6609	5287.2	3.20
7% Skylight Area	6604	5283.2	7.20
10% Skylight Area	6614	5291.2	-0.80

Table 4.20 –Energy cost ($) savings due to the proposed clerestory cases. Energy cost savings are classified into cooling, lighting, electricity, and natural gas use savings.

Clerestories	**Cooling Elec. Use(kWh)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	252773	18958.0	
2 ft glazing	251201	18840.1	117.90
3 ft glazing	253263	18994.7	-36.75
4 ft glazing	255328	19149.6	-191.63
5 ft glazing	257370	19302.8	-344.78
6 ft glazing	259394	19454.6	-496.58
Clerestories	**Total Elec. Use (kWh)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	966281	72471.1	
2 ft glazing	929764	69732.3	2738.77
3 ft glazing	932030	69902.3	2568.83
4 ft glazing	934802	70110.2	2360.93
5 ft glazing	937750	70331.3	2139.83
6 ft glazing	940778	70558.4	1912.73

Clerestories	**Lighting Elec. Use (kWh)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	242729	18204.7	
2 ft glazing	209305	15697.9	2506.80
3 ft glazing	208212	15615.9	2588.78
4 ft glazing	207629	15572.2	2632.50
5 ft glazing	207268	15545.1	2659.58
6 ft glazing	207021	15526.6	2678.10
Clerestories	**Total Natural Gas Use (CCF)**	**Cost ($)**	**Difference = Cost Savings ($)**
Base case	6613	5290.4	
2 ft glazing	6606	5284.8	5.60
3 ft glazing	6599	5279.2	11.20
4 ft glazing	6591	5272.8	17.60
5 ft glazing	6584	5267.2	23.20
6 ft glazing	6576	5260.8	29.60

Table 4.21 –Total energy cost ($) savings due to the proposed skylight and clerestory cases.

Skylights	**Total Cost ($)**	**Total Savings ($)**	**Performance rank** (most savings=1 to least savings=5)
Base case	77761.5		
1% Skylight Area	75451.2	2310.30	2
3% Skylight Area	**75192.4**	**2569.10**	**Most Savings(1)**
5% Skylight Area	75465.3	2296.18	3
7% Skylight Area	75696.0	2065.50	4
10% Skylight Area	76224.7	1536.77	Least Savings(5)
Clerestories	**Total Cost ($)**	**Total Savings ($)**	**Performance rank** (most savings =1 to least savings =5)
Base case	77761.5		
2 ft glazing	**75017.1**	**2744.37**	**Most Savings (1)**
3 ft glazing	75181.5	2580.02	2
4 ft glazing	75383.0	2378.52	3
5 ft glazing	75598.5	2163.02	4
6 ft glazing	75819.2	1942.33	Least Savings(5)

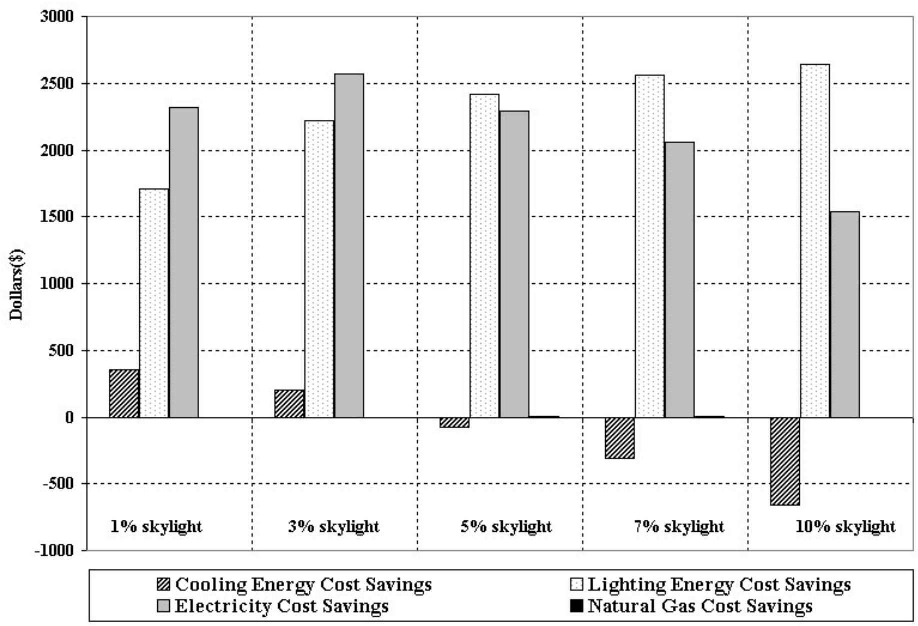


Figure 4.57 –Energy cost savings: skylights

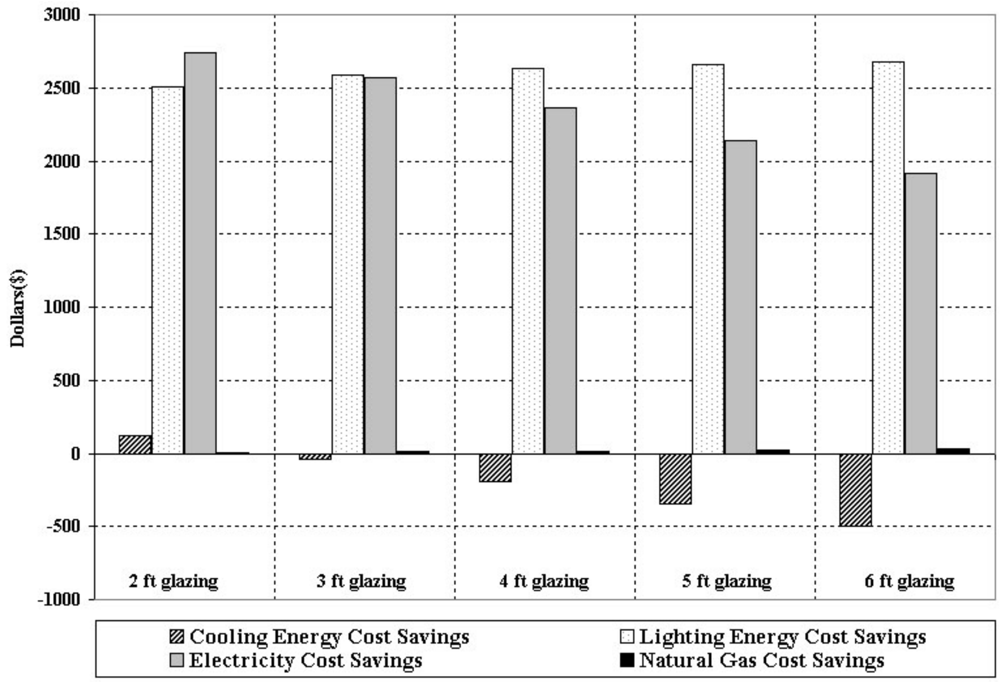


Figure 4.58 –Energy cost savings: clerestories

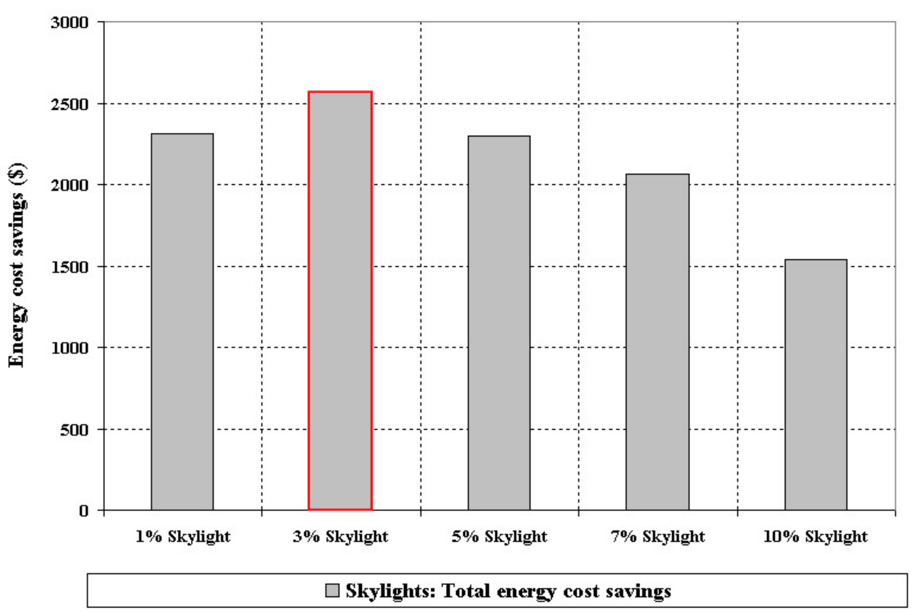


Figure 4.59 –Total energy cost savings for the proposed skylight cases

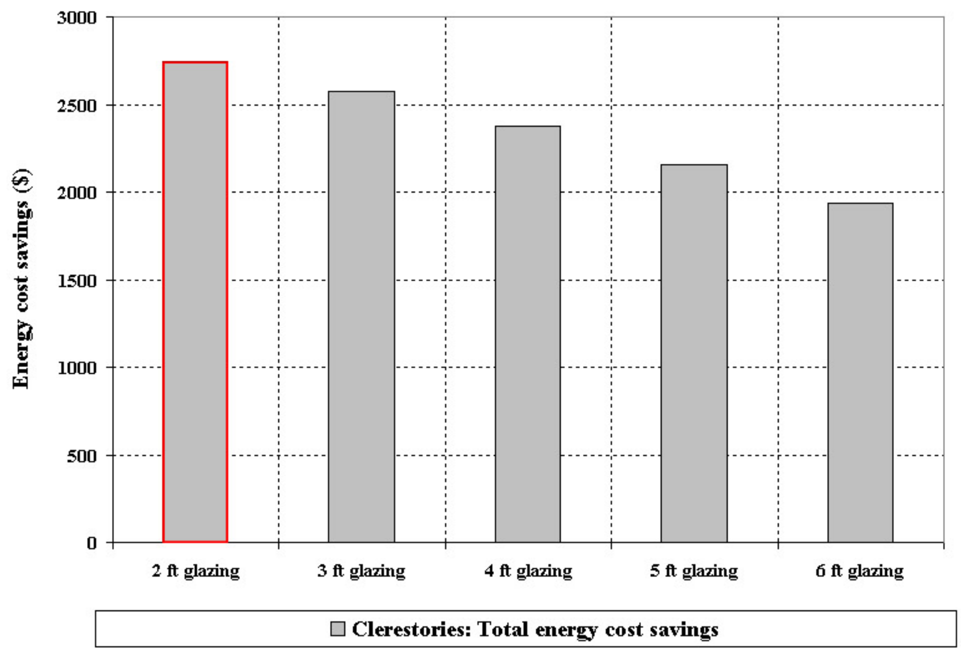


Figure 4.60 –Total energy cost savings for the proposed clerestory cases

Figures 4.57-4.58 show the energy cost savings for the skylights and clerestories. The savings are classified into cooling, lighting, electricity and natural gas use savings. Figures 4.59-4.60 show the total energy cost savings for all the proposed skylight and clerestory cases.

4.5. SUMMARY

The results of the daylighting factor analyses suggests that the use of skylight and clerestory options for the school building spaces are potent options to increase space illuminance, reduce lighting energy use, improve the overall quality of natural light, and reduce operating costs.

The 3% skylight case and the 2 ft clerestory performed the best in their respective categories for the total energy savings and the total energy cost savings. Though the 2 ft clerestory was seen to be the best among the group, the 3 ft clerestory also performed well, and in fact performed better than the 3% skylight case. This study recommends the use of a clerestory with glazing height between 2 feet and 3 feet as the best daylighting option for this case study school building. The 3% skylight case is recommended as the next best choice.

The building energy analysis suggests a considerable reduction in lighting and total electric use can be achieved through the proper size of skylights and clerestories. Heating energy use stays almost constant in all cases with small increases in the skylight cases whereas small reductions in the clerestory cases. Considering all the different trends in energy use, in the end, all the proposed cases perform better than the base case in terms of total energy savings.

Total average annual savings of more than $2000 can be achieved for the whole school building through the application of any of the modifications studied.

As only part of the school building was studied, studying the rest of the building could increase the savings. The sum of the areas of all the spaces (10 classrooms and the library) under consideration is 10500 sq. ft. This area is just 15% of the total area of the school building, which is 69,093 sq. ft. The proposed daylighting options have been restricted to this 15% area of the school building. Under the circumstances that the entire school building is daylit through the use of skylights or clerestories, the projected savings would be much higher than the calculated value. There is a huge potential for energy and cost savings in this case study school building in College Station, Texas.

Assuming that about 80% of the total built-up area of the school can be daylit, if the savings for the 15% analysis area can be used to calculate the savings for the whole school, simple extrapolated savings would be:

- Average annual lighting electricity use savings of around 66%, corresponding to $7500,
- Average annual cooling electricity use savings, natural gas use savings, and miscellaneous savings corresponding to $5500, and
- A total average annual energy savings of around 14%, corresponding to a total of $13000 in annual cost savings, could be achieved.

The total annual energy savings can be attributed 58% to lighting improvements and 42% to cooling, gas usage and other efficiencies.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to evaluate the importance of daylighting application in elementary schools in climates similar to that of College Station. The method has been explained in Chapter III of this thesis, and includes field measurements, physical modeling, computer simulation, and review of energy usage data. This chapter presents the conclusions derived from various stages in the research. The following sections present several categories of conclusions: 1) Selection of the case study site, 2) daylight evaluation at the selected school building, 3) physical scale model analysis, 4) DOE-2 base case simulation model, 5) daylighting quality comparisons, 6) methods and techniques used for study, and 7) DOE-2 energy analysis.

This research was different from past research in this field as it involved study of an existing school building through three unique methods. The literature review in Chapter II showed that previous research used hypothetical cases that did not involve a real building, and instances where a real building was involved, the methods were limited mainly to any one method, mainly computer simulations. This research can be generalized for one-storied school buildings in similar climates and cultures, in the United States and anywhere else around the world. The methods applied in this research involve the use of standardized measurement devices and simulation tools that are verifiable and hence valid. This research is significant as it provides adequate confirmation that daylighting can reduce the energy consumption in a building. It also furthers awareness towards the need to focus on renewable energy resources as a solution for world energy conservation.

5.1. SELECTION OF THE CASE STUDY SITE

The case study site is a one story elementary school in College Station, Texas. A study of all the elementary school designs in College Station revealed the fact that the case study school was typical in the sense of size, general school structure, type of construction, building features, height, number of stories, and school working period. The analysis and results of the analysis for this school will apply to all similar schools in the school district, thus benefiting the entire school system in this region and can also be applied to other schools in different regions that share similar building specifications, working schedules and climate.

The school authorities were very co-operative. An important part of this thesis constituted the visits to the school and the on-site measurements. The study of an existing building added the validity to the research and also made this study unique and original as regards to methods and data collection.

5.2. DAYLIGHT EVALUATION AT THE SELECTED SCHOOL BUILDING

The case study school building was ideal to study the effect of daylighting. The two main problems that were visible in the classrooms were: 1) dark spaces due to unavailability of sufficient daylight, and 2) glare from the windows. Every 30’x 30’ classroom was served by a 6'x 4' window, typically at the far left or far right corner of the room, depending upon the floor plan. This leads to a total dependency on artificial lighting. Fluorescent lights provided the lighting for reading and other student activities in the classrooms and library spaces. Another visible problem in the classrooms was the presence of ceiling-hung television sets that were located very close to the windows and that obstructed the daylight entering the space. The television sets increase the glare by silhouetting a shape in front of the windows.

The library was much better daylit due to the adjoining courtyard and windows. One problem is that the reading spaces in the library are towards the interior part of the library while the bookshelves are arranged along the window wall.

After an initial walk-through at the school, three design recommendations for this type of school have been suggested to maximize daylight:

1) Increase the number of windows to allow more daylight,
2) Plan classrooms around open-to-sky areas like courtyards that can serve as daylight collectors, and
3) Reading and working spaces should be given priority in their access to daylight, and daylight entry into the rooms should not be obstructed.

Daylight factors measured inside the spaces were found to be very low, and ranged from 0.1 to 0.2 %. These values are very low as compared to the IES recommended values between 2 to 3 % for reading areas. Table 6.1 shows the values for average illuminance (lux) for the different spaces. These measurements were taken with all the artificial lighting shut off in all the spaces. It can be seen that the best case is Space 1-8, which has an average interior illuminance of about 26 lux (2 footcandles). The IES average recommended value for illuminance, as mentioned earlier in the literature review is 500 to 750 lux (50-75 footcandles). The existing daylighting is extremely insufficient.

Table 5.1 – Average illuminance (in lux) for the different spaces

SPACES	1-1	1-2	1-4	1-5	1-7	1-8
Avg. Illuminance	10.76	10.16	15	17.325	9.75	26.38

5.3. PHYSICAL SCALE MODEL ANALYSIS

The use of the physical scale model was an important part of this study because it allowed me to modify the base case model to include and study different skylights and clerestories. The scale model was calibrated to the actual spaces by using materials that resembled the actual building materials used in reflectance. It was seen that daylight factors in the scale model were slightly higher than the daylight factors from the case study site. This can be attributed to various conditions in the case study spaces, like the presence of ceiling-hung television sets near the window openings, actual window transmittances, internal light reflections due to furniture and blackboards inside the classrooms, and vegetation outside the spaces that impaired the daylight. The daylight factors obtained from the modified daylighting options were important in conducting the comparison with the factors obtained from DOE-2.

5.4. THE DOE-2 BASE CASE MODEL

A base case computer model was made for the case study school building using the DOE-2 simulation software. The available building data was very useful in creating the LOADS portion of the DOE-2 input file, while the mechanical details for the SYSTEMS portion of the file were obtained from the electrical and mechanical drawings obtained from the ESL. The DrawBDL program was effective in providing the needed graphic representation of the building. The base case model was calibrated to the measured electricity and natural gas usage for the case study building. Graphical and statistical methods were used to achieve the required calibration. After the required calibration was achieved, the model was modified to include daylighting input. Daylighting functions were defined in the LOADS portion of the input file. Skylights and clerestories were defined and their effect was studied on the daylight factors in the spaces, lighting energy, cooling and heating loads, and total electricity and natural gas consumption. Two reference points were defined in every space, and the daylight factors at these points were compared to the actual space and physical model values.

The base case non-daylit DOE-2 model was compared with a base case daylit model in order to analyze the effect of daylighting on energy consumption. The daylit case was seen to perform better than the non-daylit case.

5.5. DAYLIGHT QUALITY COMPARISONS

Study of daylight quality in the spaces was one of the objectives of this research. Effect on daylight factors and interior illuminance due to the proposed designs led to optimum design selection.

Daylight factors obtained from the actual space were compared to the ones from DOE-2 and the physical scale model. The first part of this study compared the daylight factors from the case study site, DOE-2, and the physical model in order to evaluate the trends observed. The second part of the daylight factor analysis involved a comparison between the DOE-2 values and the physical model values for the proposed skylight and clerestory designs. At the base case level, the DOE-2 calculated daylight factors were seen to be similar to the physical model values, and thus were considered in the analysis. During the second stage, for the skylight cases, the DOE-2 daylight factors were seen to be consistently much lower than the physical model values, and the physical scale model was used for further daylighting calculations. The use of a functional input involved defining a user-input FUNCTION that overwrote the daylight factors calculated in DOE-2 by user-defined values obtained from the physical model. For the clerestory cases, the DOE-2 calculated daylight factors were similar or slightly higher in value than the physical model values, and the DOE-2 values were used for further calculations. Considering an average acceptable daylight factor of 2%, optimum sizes for skylights and clerestories were defined.

The daylighting output from the LOADS part of the DOE-2 simulation program was also studied to compare the percent lighting energy reduction and the average illuminance in footcandles through the use of daylighting. The trend lines for interior illuminance and daylight factors were similar for the physical model and DOE-2 simulated cases.

5.6. METHODS AND TECHNIQUES USED IN RESEARCH

The study consisted of three methods. These were: actual space measurements, physical modeling, and computer simulation. Each method linked to the other in a unique way. Site visits to the case study building were important to understand the potential of daylighting. This method involved measurement of daylight factors, illuminance, and luminance inside the spaces, all of which helped in physical model calibration. It was not time-consuming as all the measurements were completed in three visits, each visit lasting for about 2 hours. The only factor determining the effectiveness in time and accuracy was the availability of overcast sky condition when the daylight factors could be measured.

A calibrated physical model was necessary to conduct the required experiments with proposed daylighting cases. Errors were minimized in the physical scale model which increased the validity of future work. The physical model was modified to include skylights and clerestories of different sizes. Daylight factors were analyzed in every case, and were termed reliable due to earlier model calibration. These factors were used in the DOE-2 simulations so as to replace the under-predicted DOE-2 daylight factors. The physical model, though time-consuming, was an important tool to provide validity to the DOE-2 simulation results that determined the effect of daylighting on energy consumption. The absence of interior elements like furniture inside the physical model spaces did affect the daylight factor values by a small percentage, but the overall trend was seen to be consistent.

The development of the base case model in DOE-2 was time consuming as the user was an architect and not an expert in this software package that demands sufficient know-how of mechanical systems used in buildings. Adequate details in both, the LOADS and SYSTEMS portion of the input file were necessary for model accuracy. Base case model calibration was also a time consuming process due to the large building footprint. This study tried to achieve calibration up to the hourly level to minimize errors. Though being excellent software for energy analysis, DOE-2 was found to be inadequate in handling daylighting and is not recommended as ideal software for purely daylighting analysis.

5.7. ENERGY EVALUATION USING DOE-2

DOE-2 was used as the energy simulation software to study the effect of daylighting on different aspects of energy consumption. The base case non-daylit model was compared with a similar daylit model. Lighting energy showed a decrease throughout the year, whereas the cooling energy also decreased, especially in the hot season between the months of April to October. The reduction in lighting energy was seen to be more pronounced than the reduction in cooling energy. The plots for whole building electric and heating energy indicated that the model with proposed daylighting brought about a decrease in electrical energy throughout the year, but the heating energy did not show an increase for any month, and remained fairly constant throughout. The base case with daylighting was considered as base case for all future simulations.

The first stage of analysis included monthly lighting electricity usage, monthly cooling electricity usage, whole building electricity usage, and natural gas usage for the whole year. Lighting, cooling, and heating energy analysis was performed at the hourly level to better understand their effects. Lighting energy analysis was done for the four typical days of March 21, June 21, September 21, and December 21. For the skylight cases, the most savings were seen on March 21st. For the clerestory designs, most savings were observed on September 21st, followed closely by March 21st.

Cooling energy analysis was performed for September 21, the typical day with the hottest average daily outdoor dry bulb temperature, while heating energy analysis was performed on December 21, the typical day with the lowest average daily outdoor dry bulb temperature. Cooling electricity use increased with increasing skylight and clerestory sizes. This was attributed to the heat gain through the additional glazing in each of the proposed cases. The heating energy analysis did not show any trend, and heating energy remained constant throughout.

Energy analysis according to end-uses in all the cases revealed a consistent increase in the category of space cooling, while a consistent decrease in the category of area lighting. Trends in heating, cooling, and lighting were studied through line graphs and bar charts.

The last part of the energy analysis using DOE-2 was the economics. This was divided into two parts: 1) Energy savings (MBtu) due to proposed designs, and 2) Energy cost savings (dollars) due to proposed designs. The 3% skylight case was the best among the skylight cases, while the 2 ft glazing performed best in the clerestory category. In the end, the general conclusion was that all the proposed cases perform better than the base case in terms of total energy savings. Individual categories were also ranked based on their performance. The 6 ft clerestory glazing case performed best in the lighting energy and natural gas use categories, while the 1% skylight case ranked last in these two categories. The 1% skylight case was the best in cooling energy savings while the 10% skylight case was the least effective. The 2 ft clerestory glazing performed best overall (total energy) while the 10% skylight case was the least effective. Energy cost savings ($) indicated that the 3% skylight area indicates the most cost savings among all the skylight cases, while the 2 ft glazing shows most cost savings among all the clerestory cases. Overall, all designs generated savings in energy and energy costs, and a clerestory design with 2 to 3 ft of glazing height was ranked as the best among all the proposed designs, followed by the 2% skylight design. The results indicate that around $2000 can be saved annually for the entire school through the use of any of these daylighting designs. This study considers a small portion of the school for daylighting analysis, and hence the savings are not exactly proportional to the total building floor area. Future studies should evaluate effects of daylighting as applied to the entire school building.

A salient conclusion is that elementary schools built in hot, humid climates in the United States or comparable educational cultures should be provided with daylighting features.

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APPENDIX A

BASE CASE INPUT FILE FOR DOE-2 SIMULATION AND SELECTED DAYLIGHTING COMMANDS AND KEYWORDS USED IN DOE-2 DAYLIGHTING SIMULATIONS

INPUT FILE

THESIS
UMESH VINAYAK ATRE

```
*********************************************************************
INPUT LOADS  ..
TITLE           LINE-1            *GRADUATE THESIS INPUT FILE*
                LINE-2            *BASIC RUN *
                LINE-3            *FOUNTAINHEAD*
                LINE-4            *UMESH VINAYAK ATRE * ..

                RUN-PERIOD         JAN 1 2001 THRU DEC 31 2001    ..
                ABORT              ERRORS  ..
                DIAGNOSTIC         WARNINGS  ..
                LOADS-REPORT       SUMMARY=(LS-C,LS-D,LS-G,LS-H,LS-I,
                                            LS-J,LS-F)
                                   VERIFICATION=(LV-A,LV-G,LV-L) ..
                BUILDING-LOCATION  LATITUDE=30.6
                                   LONGITUDE=96.22
                                   ALTITUDE=610
                                   TIME-ZONE=6
                                   AZIMUTH=225
                                   HOLIDAY=NO  ..

$ BUILDING DESCRIPTION
$ CONSTRUCTION AND GLASS-TYPES

ROO-1    =LAYERS =MAT=(RG01,BR01,IN44,WD01)  I-F-R .76  ..

$DYNAMIC OR DELAYED WALLS (ROOFS)
$LAYERS: 1/2" ROOF GRAVEL, BUILT-UP ROOFING 3/8"
$        1.25" EXPANDED POLYURETHANE INSULATION,
$        3/4" SOFT-WOOD.

WA-1-2   =LAYERS =MAT=(BK04,AL21,GP01,IN11,GP01)  ..

$DYNAMIC OR DELAYED WALLS (EXT. WALLS)
$LAYERS: 3"FACE BRK, 1" AIR LAYER, 3/4"GYP BOARD,
$        3/4"INSULATION, 3/4"GYP BOARD.

WA-INT-1 =LAYERS =MAT=(BK01)  ..

$LAYERS: 4" COMMON BK WALL. (INT. WALLS)

CC-1     =LAYERS =MAT=(AC03)  ..

$LAYERS: 3/4" ACOUSTIC TILE. (CEILING)

FF-1     =LAYERS =MAT=(CC24,LT01)  ..

$LAYERS: 4" LIGHT WT CONCRETE, LINOLEUM.TILE.
$        (FLOORS)


ROOF-1   =CONSTRUCTION       LAYERS=ROO-1  ..        $ROOFS
WALL-1   =CONSTRUCTION       LAYERS=WA-1-2  ..       $EXTERNAL WALLS
SB-U     =CONSTRUCTION       LAYERS=WA-INT-1   ..    $INTERNAL WALLS
CLNG-1   =CONSTRUCTION       LAYERS=CC-1  ..         $DROP-CEILING
FLOOR-0  =CONSTRUCTION       LAYERS=FF-1  ..         $FLOORS

WIND-1   =GLASS-TYPE         GLASS-TYPE-CODE = 9  PANES = 1  ..
$WINDOWS
DOORS    =GLASS-TYPE         GLASS-TYPE-CODE = 9  PANES = 1   ..
$DOORS
```

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$ OCCUPANCY SCHEDULE

OC-1           =DAY-SCHEDULE       (1)(0.05) (2)(0.05) (3)(0.09)
                                   (4)(0.15) (5)(0.2) (6)(0.3) (7)(0.4)
                                   (8)(0.5) (9)(0.6) (10)(0.7) (11)(0.8)
                                   (12)(0.9) (13)(1) (14)(0.9) (15)(0.8)
                                   (16)(0.7) (17)(0.6) (18)(0.5)
                                   (19) (0.4) (20)(0.3) (21)(0.2)
                                   (22)(0.1) (23)(0.08) (24)(0.05)  ..
OC-1A           =DAY-SCHEDULE      (1)(0.35) (2)(0.45) (3)(0.46)
                                   (4)(0.48) (5)(0.5) (6)(0.55) (7)(0.58)
                                   (8)(0.65) (9)(0.7) (10)(0.75)
                                          (11)(0.78)(12)(0.8)(13)(0.81)(14)(0.8)
                                                 (15)(0.78)(16)(0.75)(17)(0.7)
                                   (18)(0.65)
                                   (19) (0.58) (20)(0.5) (21)(0.48)
                                   (22)(0.45) (23)(0.4) (24)(0.35)  ..
OC-1AA          =DAY-SCHEDULE      (1)(0.37) (2)(0.45) (3)(0.46)
                                   (4)(0.48) (5)(0.5) (6)(0.55) (7)(0.58)
                                   (8)(0.8) (9)(0.9) (10)(0.96)
                                           (11)(0.98)
                                   (12)(0.99) (13)(1) (14)(0.99)
                                           (15)(0.98)
                                   (16)(0.96) (17)(0.9) (18)(0.8)
                                   (19) (0.58) (20)(0.5) (21)(0.48)
                                   (22)(0.45) (23)(0.4) (24)(0.37)  ..
OC-2           =DAY-SCHEDULE       (1)(0.06) (2)(0.06) (3)(0.06)
                                   (4)(0.065)
                                   (5)(0.07) (6)(0.08) (7)(0.085)
                                   (8)(0.09) (9)(0.095) (10)(0.1)
                                          (11)(0.17)
                                   (12)(0.2) (13)(0.17) (14)(0.1)
                                          (15)(0.09)
                                   (16)(0.08) (17)(0.07) (18)(0.065)
                                   (19,20) (0.06) (21,22)(0.06)
                                   (23,24)(0.06) ..
OC-21           =DAY-SCHEDULE      (1)(0.2) (2)(0.21) (3)(0.22)
                                   (4)(0.23)
                                   (5)(0.24) (6)(0.25) (7)(0.26)
                                   (8)(0.27) (9)(0.28) (10)(0.3)
                                          (11)(0.32)
                                   (12)(0.34) (13)(0.36) (14)(0.34)
                                          (15)(0.32)
                                   (16)(0.3) (17)(0.28) (18)(0.25)
                                   (19,20) (0.22) (21,22)(0.21)
                                   (23,24)(0.2) ..
OC-2A           =DAY-SCHEDULE      (1)(0.1) (2)(0.15) (3)(0.18)
                                   (4)(0.2)
                                   (5)(0.22) (6)(0.24) (7)(0.27)
                                   (8)(0.4) (9)(0.54) (10)(0.57)
                                          (11)(0.58)
                                   (12)(0.6) (13)(0.62) (14)(0.6)
                                           (15)(0.58)
                                   (16)(0.57) (17)(0.54) (18)(0.4)
                                   (19,20) (0.27) (21,22)(0.15)
                                   (23,24)(0.1) ..
OC-2AA           =DAY-SCHEDULE     (1,11)(0.5)
                                   (12)(0.4) (13)(0.35) (14)(0.34)
                                           (15)(0.4)
                                   (16)(0.43) (17)(0.45) (18)(0.3)
                                   (19,20) (0.15) (21,22)(0.1)
                                   (23,24)(0.07) ..
OC-2B           =DAY-SCHEDULE      (1)(0.4) (2)(0.42) (3)(0.45)
                                   (4)(0.47)
                                   (5)(0.48) (6)(0.49) (7)(0.5)
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                                        (8)(0.52) (9)(0.54) (10)(0.55)
                                                (11)(0.58)
                                        (12)(0.59) (13)(0.6) (14)(0.58)
                                                (15)(0.56)
                                        (16)(0.54) (17)(0.5) (18)(0.48)
                                        (19,20) (0.4) (21,22)(0.35)
                                        (23,24)(0.3) ..
OC-3            =DAY-SCHEDULE           (1)(0.025) (2)(0.026) (3)(0.027)
                                               (4)(0.03)
                                        (5)(0.035) (6)(0.036) (7)(0.037)
                                        (8)(0.38) (9)(0.4) (10)(0.8)
                                               (11)(0.85)
                                        (12)(0.875) (13)(0.33) (14)(0.15)
                                        (15)(0.05)
                                        (16)(0.04) (17)(0.03) (18)(0.028)
                                        (19,20) (0.027) (21,22)(0.026)
                                        (23,24)(0.025) ..
OC-4            =DAY-SCHEDULE           (1)(0.05) (2)(0.05) (3)(0.06)
                                        (4)(0.08)
                                        (5)(0.09) (6)(0.1) (7)(0.15)
                                        (8)(0.4) (9)(0.5) (10)(0.6) (11)(0.63)
                                        (12)(0.65) (13)(0.68) (14)(0.65)
                                               (15)(0.63)
                                        (16)(0.6) (17)(0.5) (18)(0.4)
                                        (19,20) (0.15) (21,22)(0.08)
                                        (23,24)(0.05) ..
OC-41            =DAY-SCHEDULE          (1)(0.12) (2)(0.15) (3)(0.18)
                                        (4)(0.2)
                                        (5)(0.25) (6)(0.3) (7)(0.55)
                                        (8)(0.66) (9)(0.7) (10)(0.72)
                                               (11)(0.75)
                                        (12)(0.76) (13)(0.77) (14)(0.76)
                                               (15)(0.75)
                                        (16)(0.72) (17)(0.7) (18)(0.66)
                                        (19,20) (0.5) (21,22)(0.25)
                                        (23,24)(0.12) ..
OC-41A           =DAY-SCHEDULE          (1)(0.12) (2)(0.15) (3)(0.18)
                                        (4)(0.2)
                                        (5)(0.22) (6)(0.24) (7)(0.4)
                                        (8)(0.5) (9)(0.57) (10)(0.61)
                                               (11)(0.65)
                                        (12)(0.66) (13)(0.67) (14)(0.66)
                                               (15)(0.65)
                                        (16)(0.61) (17)(0.57) (18)(0.5)
                                        (19,20) (0.4) (21,22)(0.15)
                                        (23,24)(0.12) ..
OC-42            =DAY-SCHEDULE          (1)(0.05) (2)(0.05) (3)(0.09)
                                        (4)(0.15)
                                        (5)(0.2) (6)(0.35) (7)(0.4)
                                        (8)(0.5) (9)(0.55) (10)(0.6) (11)(0.7)
                                        (12)(0.72) (13)(0.74) (14)(0.72)
                                               (15)(0.7)
                                        (16)(0.6) (17)(0.55) (18)(0.5)
                                        (19) (0.4) (20)(0.3) (21)(0.2)
                                        (22)(0.1) (23)(0.08) (24)(0.05)  ..
OC-5            =DAY-SCHEDULE           (1)(0.05) (2)(0.05) (3)(0.09)
                                        (4)(0.1)
                                        (5)(0.15) (6)(0.2) (7)(0.22)
                                        (8)(0.27) (9)(0.3) (10)(0.33)
                                               (11)(0.35)
                                        (12)(0.38) (13)(0.4) (14)(0.37)
                                                (15)(0.35)
                                        (16)(0.3) (17)(0.28) (18)(0.25)
                                        (19) (0.2) (20)(0.15) (21)(0.1)
                                        (22)(0.08) (23)(0.06) (24)(0.05)  ..
OC-5A           =DAY-SCHEDULE           (1)(0.062) (2)(0.065) (3)(0.07)
                                        (4)(0.075)
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                                  (5)(0.08) (6)(0.081) (7)(0.085)
                                  (8)(0.086) (9)(0.087) (10)(0.09)
                                         (11)(0.1)
                                  (12)(0.14) (13)(0.16) (14)(0.14)
                                         (15)(0.1)
                                  (16)(0.09) (17)(0.088) (18)(0.08)
                                  (19) (0.075) (20)(0.072) (21)(0.07)
                                  (22)(0.065) (23)(0.062) (24)(0.062) ..
OC-6           =DAY-SCHEDULE      (1)(0.05) (2)(0.05) (3)(0.09)
                                  (4)(0.1)
                                  (5)(0.15) (6)(0.2) (7)(0.22)
                                  (8)(0.27) (9)(0.3) (10)(0.33)
                                         (11)(0.35)
                                  (12)(0.38) (13)(0.4) (14)(0.37)
                                          (15)(0.35)
                                  (16)(0.3) (17)(0.28) (18)(0.25)
                                  (19) (0.2) (20)(0.15) (21)(0.1)
                                  (22)(0.08) (23)(0.06) (24)(0.05)  ..
OC-6A           =DAY-SCHEDULE     (1)(0.05) (2)(0.05) (3)(0.09)
                                  (4)(0.1)
                                  (5)(0.15) (6)(0.2) (7)(0.22)
                                  (8)(0.27) (9)(0.36) (10)(0.4)
                                         (11)(0.47)
                                  (12)(0.52) (13)(0.55) (14)(0.52)
                                         (15)(0.47)
                                  (16)(0.4) (17)(0.36) (18)(0.27)
                                  (19) (0.2) (20)(0.15) (21)(0.1)
                                  (22)(0.08) (23)(0.06) (24)(0.05)  ..
OC-11           =DAY-SCHEDULE     (1)(0.05) (2)(0.05) (3)(0.09)
                                  (4)(0.15)
                                  (5)(0.2) (6)(0.3) (7)(0.4)
                                  (8)(0.5) (9)(0.8) (10)(0.85) (11)(0.9)
                                  (12)(0.95) (13)(1) (14)(0.95)
                                         (15)(0.9)
                                  (16)(0.85) (17)(0.8) (18)(0.7)
                                  (19) (0.5) (20)(0.3) (21)(0.2)
                                  (22)(0.09) (23)(0.08) (24)(0.05)  ..
OC-11A           =DAY-SCHEDULE    (1)(0.09) (2)(0.1) (3)(0.2)
                                  (4)(0.45)
                                  (5)(0.5) (6)(0.55) (7)(0.8)
                                  (8)(0.88) (9)(0.92) (10)(0.95)
                                        (11)(0.97)
                                  (12)(0.99) (13)(1) (14)(0.99)
                                         (15)(0.97)
                                  (16)(0.95) (17)(0.92) (18)(0.88)
                                  (19) (0.8) (20)(0.55) (21)(0.5)
                                  (22)(0.45) (23)(0.2) (24)(0.09)  ..
OC-11B           =DAY-SCHEDULE    (1)(0.09) (2)(0.1) (3)(0.11)
                                  (4)(0.2)
                                  (5)(0.25) (6)(0.35) (7)(0.6)
                                  (8)(0.8) (9)(0.88) (10)(0.9)
                                         (11)(0.97)
                                  (12)(1) (13)(1) (14)(1) (15)(0.97)
                                  (16)(0.9) (17)(0.88) (18)(0.8)
                                  (19) (0.66) (20)(0.65) (21)(0.63)
                                  (22)(0.62) (23)(0.61) (24)(0.6)  ..

OC-WEEK        =WEEK-SCHEDULE     (WD) OC-1 (WEH) OC-2  ..
OC-WEEKA       =WEEK-SCHEDULE     (WD) OC-1A (WEH) OC-2B  ..
OC-WEEKAA      =WEEK-SCHEDULE     (WD) OC-1AA (WEH) OC-2B  ..
OC-WEEK1       =WEEK-SCHEDULE     (WD) OC-4 (WEH) OC-2  ..
OC-WEEK1A      =WEEK-SCHEDULE     (WD) OC-4 (WEH) OC-4  ..
OC-WEEK2       =WEEK-SCHEDULE     (WD) OC-5 (WEH) OC-2  ..
OC-WEEK2A      =WEEK-SCHEDULE     (WD) OC-5A (WEH) OC-2  ..
OC-WEEK3       =WEEK-SCHEDULE     (WD) OC-6 (WEH) OC-2  ..
OC-WEEK3A      =WEEK-SCHEDULE     (WD) OC-6A (WEH) OC-2  ..
OC-WEEK4       =WEEK-SCHEDULE     (WD) OC-11 (WEH) OC-2  ..
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OC-WEEK4A       =WEEK-SCHEDULE      (WD) OC-11A (WEH) OC-2A  ..
OC-WEEK4B       =WEEK-SCHEDULE      (WD) OC-11B (WEH) OC-2AA  ..
OC-WEEK5        =WEEK-SCHEDULE      (WD) OC-41 (WEH) OC-21  ..
OC-WEEK5A       =WEEK-SCHEDULE      (WD) OC-41A (WEH) OC-21  ..
OC-WEEK7        =WEEK-SCHEDULE      (WD) OC-42 (WEH) OC-2  ..

OCCUPY-1        =SCHEDULE           THRU JAN 1 OC-WEEK2A
                                    THRU JAN 3 OC-WEEK2
                                    THRU JAN 7 OC-WEEK7
                                    THRU JAN 10 OC-WEEK3A
                                    THRU JAN 14 OC-WEEK7
                                    THRU JAN 15 OC-WEEK2
                                    THRU FEB 7 OC-WEEK7
                                    THRU FEB 8 OC-WEEK4
                                    THRU FEB 12 OC-WEEK7
                                    THRU FEB 15 OC-WEEK4
                                    THRU FEB 22 OC-WEEK7
                                    THRU FEB 23 OC-WEEK3A
                                    THRU FEB 26 OC-WEEK
                                    THRU MAR 9 OC-WEEK7
                                    THRU MAR 18 OC-WEEK2
                                    THRU MAR 31 OC-WEEK7
                                    THRU APR 12 OC-WEEK
                                    THRU APR 15 OC-WEEK3A
                                    THRU APR 18 OC-WEEK7
                                    THRU APR 23 OC-WEEK
                                    THRU APR 29 OC-WEEK7
                                    THRU MAY 25 OC-WEEK4
                                    THRU MAY 26 OC-WEEK1A
                                    THRU JUN 8 OC-WEEK7
                                    THRU JUN 24 OC-WEEK5
                                    THRU JUL 2 OC-WEEK3A
                                    THRU JUL 28 OC-WEEK5A
                                    THRU AUG 10 OC-WEEKA
                                    THRU AUG 12 OC-WEEK5A
                                    THRU AUG 15 OC-WEEKA
                                    THRU SEP 2 OC-WEEK4A
                                    THRU SEP 3 OC-WEEK1
                                    THRU SEP 9 OC-WEEK4A
                                    THRU SEP 17 OC-WEEK
                                    THRU SEP 19 OC-WEEKA
                                    THRU SEP 20 OC-WEEKAA
                                    THRU OCT 5 OC-WEEK
                                    THRU OCT 8 OC-WEEK7
                                    THRU OCT 15 OC-WEEK
                                    THRU OCT 18 OC-WEEK7
                                    THRU OCT 21 OC-WEEK
                                    THRU OCT 24 OC-WEEK4
                                    THRU NOV 2 OC-WEEK
                                    THRU NOV 3 OC-WEEK4B
                                    THRU NOV 16 OC-WEEK4
                                    THRU NOV 20 OC-WEEK
                                    THRU NOV 25 OC-WEEK3
                                    THRU NOV 26 OC-WEEK
                                    THRU DEC 3 OC-WEEK7
                                    THRU DEC 8 OC-WEEK4
                                    THRU DEC 20 OC-WEEK7
                                    THRU DEC 31 OC-WEEK2A ..

$ LIGHTING SCHEDULE


LT-1            =DAY-SCHEDULE       (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.15)
                                    (5)(0.2) (6)(0.3) (7)(0.4)
                                    (8)(0.5) (9)(0.6) (10)(0.7) (11)(0.8)
                                    (12)(0.9) (13)(1) (14)(0.9) (15)(0.8)
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                                    (16)(0.7) (17)(0.6) (18)(0.5)
                                    (19) (0.4) (20)(0.3) (21)(0.2)
                                    (22)(0.1) (23)(0.08) (24)(0.05)  ..
LT-1A           =DAY-SCHEDULE       (1)(0.35) (2)(0.45) (3)(0.46)
                                    (4)(0.48)
                                    (5)(0.5) (6)(0.55) (7)(0.58)
                                    (8)(0.65) (9)(0.7) (10)(0.75) (11)(0.78)
                                    (12)(0.8) (13)(0.81) (14)(0.8) (15)(0.78)
                                    (16)(0.75) (17)(0.7) (18)(0.65)
                                    (19) (0.58) (20)(0.5) (21)(0.48)
                                    (22)(0.45) (23)(0.4) (24)(0.35)  ..

LT-1AA          =DAY-SCHEDULE       (1)(0.37) (2)(0.45) (3)(0.46)
                                    (4)(0.48)
                                    (5)(0.5) (6)(0.55) (7)(0.58)
                                    (8)(0.8) (9)(0.9) (10)(0.96) (11)(0.98)
                                    (12)(0.99) (13)(1) (14)(0.99) (15)(0.98)
                                    (16)(0.96) (17)(0.9) (18)(0.8)
                                    (19) (0.58) (20)(0.5) (21)(0.48)
                                    (22)(0.45) (23)(0.4) (24)(0.37)  ..
LT-2           =DAY-SCHEDULE        (1)(0.06) (2)(0.06) (3)(0.06)
                                    (4)(0.065)
                                    (5)(0.07) (6)(0.08) (7)(0.085)
                                    (8)(0.09) (9)(0.095) (10)(0.1) (11)(0.17)
                                    (12)(0.2) (13)(0.17) (14)(0.1) (15)(0.09)
                                    (16)(0.08) (17)(0.07) (18)(0.065)
                                    (19,20) (0.06) (21,22)(0.06)
                                    (23,24)(0.06) ..
LT-2A           =DAY-SCHEDULE       (1)(0.1) (2)(0.15) (3)(0.18)
                                    (4)(0.2)
                                    (5)(0.22) (6)(0.24) (7)(0.27)
                                    (8)(0.4) (9)(0.54) (10)(0.57) (11)(0.58)
                                    (12)(0.6) (13)(0.62) (14)(0.6) (15)(0.58)
                                    (16)(0.57) (17)(0.54) (18)(0.4)
                                    (19,20) (0.27) (21,22)(0.15)
                                    (23,24)(0.1) ..
LT-2AA           =DAY-SCHEDULE      (1,11)(0.5)
                                    (12)(0.4) (13)(0.35) (14)(0.34) (15)(0.4)
                                    (16)(0.43) (17)(0.45) (18)(0.3)
                                    (19,20) (0.15) (21,22)(0.1)
                                    (23,24)(0.07) ..
LT-2B           =DAY-SCHEDULE       (1)(0.4) (2)(0.42) (3)(0.45)
                                    (4)(0.47)
                                    (5)(0.48) (6)(0.49) (7)(0.5)
                                    (8)(0.52) (9)(0.54) (10)(0.55) (11)(0.58)
                                    (12)(0.59) (13)(0.6) (14)(0.58) (15)(0.56)
                                    (16)(0.54) (17)(0.5) (18)(0.48)
                                    (19,20) (0.4) (21,22)(0.35)
                                    (23,24)(0.3) ..
LT-21           =DAY-SCHEDULE       (1)(0.2) (2)(0.21) (3)(0.22)
                                    (4)(0.23)
                                    (5)(0.24) (6)(0.25) (7)(0.26)
                                    (8)(0.27) (9)(0.28) (10)(0.3) (11)(0.32)
                                    (12)(0.34) (13)(0.36) (14)(0.34) (15)(0.32)
                                    (16)(0.3) (17)(0.28) (18)(0.25)
                                    (19,20) (0.22) (21,22)(0.21)
                                    (23,24)(0.2) ..
LT-3           =DAY-SCHEDULE        (1)(0.025) (2)(0.026) (3)(0.027) (4)(0.03)
                                    (5)(0.035) (6)(0.036) (7)(0.037)
                                    (8)(0.38) (9)(0.4) (10)(0.8) (11)(0.85)
                                    (12)(0.875) (13)(0.33) (14)(0.15)
                                    (15)(0.05)
                                    (16)(0.04) (17)(0.03) (18)(0.028)
                                    (19,20) (0.027) (21,22)(0.026)
                                    (23,24)(0.025) ..
LT-4           =DAY-SCHEDULE        (1)(0.05) (2)(0.05) (3)(0.06)
                                    (4)(0.08)
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                                    (5)(0.09) (6)(0.1) (7)(0.15)
                                    (8)(0.4) (9)(0.5) (10)(0.6) (11)(0.63)
                                    (12)(0.65) (13)(0.68) (14)(0.65) (15)(0.63)
                                    (16)(0.6) (17)(0.5) (18)(0.4)
                                    (19,20) (0.15) (21,22)(0.08)
                                    (23,24)(0.05) ..
LT-41           =DAY-SCHEDULE       (1)(0.12) (2)(0.15) (3)(0.18)
                                    (4)(0.2)
                                    (5)(0.25) (6)(0.3) (7)(0.55)
                                    (8)(0.66) (9)(0.7) (10)(0.72) (11)(0.75)
                                    (12)(0.76) (13)(0.77) (14)(0.76) (15)(0.75)
                                    (16)(0.72) (17)(0.7) (18)(0.66)
                                    (19,20) (0.5) (21,22)(0.25)
                                    (23,24)(0.12) ..

LT-41A          =DAY-SCHEDULE       (1)(0.12) (2)(0.15) (3)(0.18)
                                    (4)(0.2)
                                    (5)(0.22) (6)(0.24) (7)(0.4)
                                    (8)(0.5) (9)(0.57) (10)(0.61) (11)(0.65)
                                    (12)(0.66) (13)(0.67) (14)(0.66) (15)(0.65)
                                    (16)(0.61) (17)(0.57) (18)(0.5)
                                    (19,20) (0.4) (21,22)(0.15)
                                    (23,24)(0.12) ..
LT-42           =DAY-SCHEDULE       (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.15)
                                    (5)(0.2) (6)(0.35) (7)(0.4)
                                    (8)(0.5) (9)(0.55) (10)(0.6) (11)(0.7)
                                    (12)(0.72) (13)(0.74) (14)(0.72) (15)(0.7)
                                    (16)(0.6) (17)(0.55) (18)(0.5)
                                    (19) (0.4) (20)(0.3) (21)(0.2)
                                    (22)(0.1) (23)(0.08) (24)(0.05)  ..
LT-5           =DAY-SCHEDULE        (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.1)
                                    (5)(0.15) (6)(0.2) (7)(0.22)
                                    (8)(0.27) (9)(0.3) (10)(0.33) (11)(0.35)
                                    (12)(0.38) (13)(0.4) (14)(0.37) (15)(0.35)
                                    (16)(0.3) (17)(0.28) (18)(0.25)
                                    (19) (0.2) (20)(0.15) (21)(0.1)
                                    (22)(0.08) (23)(0.06) (24)(0.05)  ..
LT-5A          =DAY-SCHEDULE        (1)(0.062) (2)(0.065) (3)(0.07)
                                    (4)(0.075)
                                    (5)(0.08) (6)(0.081) (7)(0.085)
                                    (8)(0.086) (9)(0.087) (10)(0.09) (11)(0.1)
                                    (12)(0.14) (13)(0.16) (14)(0.14) (15)(0.1)
                                    (16)(0.09) (17)(0.088) (18)(0.08)
                                    (19) (0.075) (20)(0.072) (21)(0.07)
                                    (22)(0.065) (23)(0.062) (24)(0.062)  ..
LT-6           =DAY-SCHEDULE        (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.1)
                                    (5)(0.15) (6)(0.2) (7)(0.22)
                                    (8)(0.27) (9)(0.3) (10)(0.33) (11)(0.35)
                                    (12)(0.38) (13)(0.4) (14)(0.37) (15)(0.35)
                                    (16)(0.3) (17)(0.28) (18)(0.25)
                                    (19) (0.2) (20)(0.15) (21)(0.1)
                                    (22)(0.08) (23)(0.06) (24)(0.05)  ..
LT-6A           =DAY-SCHEDULE       (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.1)
                                    (5)(0.15) (6)(0.2) (7)(0.22)
                                    (8)(0.27) (9)(0.36) (10)(0.4) (11)(0.47)
                                    (12)(0.52) (13)(0.55) (14)(0.52) (15)(0.47)
                                    (16)(0.4) (17)(0.36) (18)(0.27)
                                    (19) (0.2) (20)(0.15) (21)(0.1)
                                    (22)(0.08) (23)(0.06) (24)(0.05)  ..
LT-11           =DAY-SCHEDULE       (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.15)
                                    (5)(0.2) (6)(0.3) (7)(0.4)
                                    (8)(0.5) (9)(0.8) (10)(0.85) (11)(0.9)
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                                   (12)(0.95) (13)(1) (14)(0.95) (15)(0.9)
                                   (16)(0.85) (17)(0.8) (18)(0.7)
                                   (19) (0.5) (20)(0.3) (21)(0.2)
                                   (22)(0.09) (23)(0.08) (24)(0.05)  ..
LT-11A           =DAY-SCHEDULE     (1)(0.09) (2)(0.1) (3)(0.2)
                                   (4)(0.45)
                                   (5)(0.5) (6)(0.55) (7)(0.8)
                                   (8)(0.88) (9)(0.92) (10)(0.95) (11)(0.97)
                                   (12)(0.99) (13)(1) (14)(0.99) (15)(0.97)
                                   (16)(0.95) (17)(0.92) (18)(0.88)
                                   (19) (0.8) (20)(0.55) (21)(0.5)
                                   (22)(0.45) (23)(0.2) (24)(0.09)  ..

LT-11B           =DAY-SCHEDULE     (1)(0.09) (2)(0.1) (3)(0.11)
                                   (4)(0.2)
                                   (5)(0.25) (6)(0.35) (7)(0.6)
                                   (8)(0.8) (9)(0.88) (10)(0.9) (11)(0.97)
                                   (12)(1) (13)(1) (14)(1) (15)(0.97)
                                   (16)(0.9) (17)(0.88) (18)(0.8)
                                   (19) (0.66) (20)(0.65) (21)(0.63)
                                   (22)(0.62) (23)(0.61) (24)(0.6)  ..

LT-WEEK        =WEEK-SCHEDULE      (MON,FRI) LT-1   (WEH) LT-2  ..
LT-WEEKA       =WEEK-SCHEDULE      (WD) LT-1A (WEH) LT-2B  ..
LT-WEEKAA      =WEEK-SCHEDULE      (WD) LT-1AA (WEH) LT-2B  ..
LT-WEEK1       =WEEK-SCHEDULE      (WD) LT-4 (WEH) LT-2  ..
LT-WEEK1A      =WEEK-SCHEDULE      (WD) LT-4 (WEH) LT-4  ..
$LT-WEEK1B     =WEEK-SCHEDULE      (WD) LT-2B (WEH) LT-2B  ..
LT-WEEK2       =WEEK-SCHEDULE      (WD) LT-5 (WEH) LT-2  ..
LT-WEEK2A      =WEEK-SCHEDULE      (WD) LT-5A (WEH) LT-2  ..
LT-WEEK3       =WEEK-SCHEDULE      (WD) LT-6 (WEH) LT-2  ..
LT-WEEK3A      =WEEK-SCHEDULE      (WD) LT-6A (WEH) LT-2  ..
LT-WEEK4A      =WEEK-SCHEDULE      (WD) LT-11A (WEH) LT-2A  ..
LT-WEEK4B      =WEEK-SCHEDULE      (WD) LT-11B (WEH) LT-2AA  ..
LT-WEEK4       =WEEK-SCHEDULE      (WD) LT-11 (WEH) LT-2  ..
LT-WEEK5       =WEEK-SCHEDULE      (WD) LT-41 (WEH) LT-21  ..
LT-WEEK5A      =WEEK-SCHEDULE      (WD) LT-41A (WEH) LT-21  ..
LT-WEEK7       =WEEK-SCHEDULE      (WD) LT-42 (WEH) LT-2  ..

LIGHTS-1       =SCHEDULE           THRU JAN 1 LT-WEEK2A
                                   THRU JAN 3 LT-WEEK2
                                   THRU JAN 7 LT-WEEK7
                                   THRU JAN 10 LT-WEEK3A
                                   THRU JAN 14 LT-WEEK7
                                   THRU JAN 15 LT-WEEK2
                                   THRU FEB 7 LT-WEEK7
                                   THRU FEB 8 LT-WEEK4
                                   THRU FEB 12 LT-WEEK7
                                   THRU FEB 15 LT-WEEK4
                                   THRU FEB 22 LT-WEEK7
                                   THRU FEB 23 LT-WEEK3A
                                   THRU FEB 26 LT-WEEK
                                   THRU MAR 9 LT-WEEK7
                                   THRU MAR 18 LT-WEEK2
                                   THRU MAR 31 LT-WEEK7
                                   THRU APR 12 LT-WEEK
                                   THRU APR 15 LT-WEEK3A
                                   THRU APR 18 LT-WEEK7
                                   THRU APR 23 LT-WEEK
                                   THRU APR 29 LT-WEEK7
                                   THRU MAY 25 LT-WEEK4
                                   THRU MAY 26 LT-WEEK1A
                                   THRU JUN 8 LT-WEEK7
                                   THRU JUN 24 LT-WEEK5
                                   THRU JUL 2 LT-WEEK3A
                                   THRU JUL 28 LT-WEEK5A
                                   THRU AUG 10 LT-WEEKA
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                                  THRU AUG 12 LT-WEEK5A
                                  THRU AUG 15 LT-WEEKA
                                  THRU SEP 2 LT-WEEK4A
                                  THRU SEP 3 LT-WEEK1
                                  THRU SEP 9 LT-WEEK4A
                                  THRU SEP 17 LT-WEEK
                                  THRU SEP 19 LT-WEEKA
                                  THRU SEP 20 LT-WEEKAA
                                  THRU OCT 5 LT-WEEK
                                  THRU OCT 8 LT-WEEK7
                                  THRU OCT 15 LT-WEEK
                                  THRU OCT 18 LT-WEEK7
                                  THRU OCT 21 LT-WEEK
                                  THRU OCT 24 LT-WEEK4
                                  THRU NOV 2 LT-WEEK
                                  THRU NOV 3 LT-WEEK4B
                                  THRU NOV 16 LT-WEEK4
                                  THRU NOV 20 LT-WEEK
                                  THRU NOV 25 LT-WEEK3
                                  THRU NOV 26 LT-WEEK
                                  THRU DEC 3 LT-WEEK7
                                  THRU DEC 8 LT-WEEK4
                                  THRU DEC 20 LT-WEEK7
                                  THRU DEC 31 LT-WEEK2A ..

$ OFFICE EQUIPMENT SCHEDULE $$$$$$$$$$$$$


EQ-1           =DAY-SCHEDULE      (1)(0.05) (2)(0.05) (3)(0.09)
                                  (4)(0.15)
                                  (5)(0.2) (6)(0.3) (7)(0.4)
                                  (8)(0.5) (9)(0.6) (10)(0.7) (11)(0.8)
                                  (12)(0.9) (13)(1) (14)(0.9) (15)(0.8)
                                  (16)(0.7) (17)(0.6) (18)(0.5)
                                  (19) (0.4) (20)(0.3) (21)(0.2)
                                  (22)(0.1) (23)(0.08) (24)(0.05)  ..
EQ-1A           =DAY-SCHEDULE     (1)(0.35) (2)(0.45) (3)(0.46)
                                  (4)(0.48)
                                  (5)(0.5) (6)(0.55) (7)(0.58)
                                  (8)(0.65) (9)(0.7) (10)(0.75) (11)(0.78)
                                  (12)(0.8) (13)(0.81) (14)(0.8) (15)(0.78)
                                  (16)(0.75) (17)(0.7) (18)(0.65)
                                  (19) (0.58) (20)(0.5) (21)(0.48)
                                  (22)(0.45) (23)(0.4) (24)(0.35)  ..
EQ-1AA          =DAY-SCHEDULE     (1)(0.37) (2)(0.45) (3)(0.46)
                                  (4)(0.48)
                                  (5)(0.5) (6)(0.55) (7)(0.58)
                                  (8)(0.8) (9)(0.9) (10)(0.96) (11)(0.98)
                                  (12)(0.99) (13)(1) (14)(0.99) (15)(0.98)
                                  (16)(0.96) (17)(0.9) (18)(0.8)
                                  (19) (0.58) (20)(0.5) (21)(0.48)
                                  (22)(0.45) (23)(0.4) (24)(0.37)  ..
EQ-2           =DAY-SCHEDULE      (1)(0.06) (2)(0.06) (3)(0.06)
                                  (4)(0.065)
                                  (5)(0.07) (6)(0.08) (7)(0.085)
                                  (8)(0.09) (9)(0.095) (10)(0.1) (11)(0.17)
                                  (12)(0.2) (13)(0.17) (14)(0.1) (15)(0.09)
                                  (16)(0.08) (17)(0.07) (18)(0.065)
                                  (19,20) (0.06) (21,22)(0.06)
                                  (23,24)(0.06) ..
EQ-2A           =DAY-SCHEDULE     (1)(0.1) (2)(0.15) (3)(0.18)
                                  (4)(0.2)
                                  (5)(0.22) (6)(0.24) (7)(0.27)
                                  (8)(0.4) (9)(0.54) (10)(0.57) (11)(0.58)
                                  (12)(0.6) (13)(0.62) (14)(0.6) (15)(0.58)
                                  (16)(0.57) (17)(0.54) (18)(0.4)
                                  (19,20) (0.27) (21,22)(0.15)
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                                         (23,24)(0.1) ..
EQ-2AA          =DAY-SCHEDULE            (1,11)(0.5)
                                         (12)(0.4) (13)(0.35) (14)(0.34) (15)(0.4)
                                         (16)(0.43) (17)(0.45) (18)(0.3)
                                         (19,20) (0.15) (21,22)(0.1)
                                         (23,24)(0.07) ..
EQ-2B           =DAY-SCHEDULE            (1)(0.4) (2)(0.42) (3)(0.45)
                                         (4)(0.47)
                                         (5)(0.48) (6)(0.49) (7)(0.5)
                                         (8)(0.52) (9)(0.54) (10)(0.55) (11)(0.58)
                                         (12)(0.59) (13)(0.6) (14)(0.58) (15)(0.56)
                                         (16)(0.54) (17)(0.5) (18)(0.48)
                                         (19,20) (0.4) (21,22)(0.35)
                                         (23,24)(0.3) ..
EQ-21           =DAY-SCHEDULE            (1)(0.2) (2)(0.21) (3)(0.22)
                                         (4)(0.23)
                                         (5)(0.24) (6)(0.25) (7)(0.26)
                                         (8)(0.27) (9)(0.28) (10)(0.3) (11)(0.32)
                                         (12)(0.34) (13)(0.36) (14)(0.34) (15)(0.32)
                                         (16)(0.3) (17)(0.28) (18)(0.25)
                                         (19,20) (0.22) (21,22)(0.21)
                                         (23,24)(0.2) ..
EQ-3            =DAY-SCHEDULE            (1)(0.025) (2)(0.026) (3)(0.027) (4)(0.03)
                                         (5)(0.035) (6)(0.036) (7)(0.037)
                                         (8)(0.38) (9)(0.4) (10)(0.8) (11)(0.85)
                                         (12)(0.875) (13)(0.33) (14)(0.15)
                                         (15)(0.05)
                                         (16)(0.04) (17)(0.03) (18)(0.028)
                                         (19,20) (0.027) (21,22)(0.026)
                                         (23,24)(0.025) ..
EQ-4            =DAY-SCHEDULE            (1)(0.05) (2)(0.05) (3)(0.06)
                                         (4)(0.08)
                                         (5)(0.09) (6)(0.1) (7)(0.15)
                                         (8)(0.4) (9)(0.5) (10)(0.6) (11)(0.63)
                                         (12)(0.65) (13)(0.68) (14)(0.65) (15)(0.63)
                                         (16)(0.6) (17)(0.5) (18)(0.4)
                                         (19,20) (0.15) (21,22)(0.08)
                                         (23,24)(0.05) ..
EQ-41           =DAY-SCHEDULE            (1)(0.12) (2)(0.15) (3)(0.18)
                                         (4)(0.2)
                                         (5)(0.25) (6)(0.3) (7)(0.55)
                                         (8)(0.66) (9)(0.7) (10)(0.72) (11)(0.75)
                                         (12)(0.76) (13)(0.77) (14)(0.76) (15)(0.75)
                                         (16)(0.72) (17)(0.7) (18)(0.66)
                                         (19,20) (0.5) (21,22)(0.25)
                                         (23,24)(0.12) ..
EQ-41A          =DAY-SCHEDULE            (1)(0.12) (2)(0.15) (3)(0.18)
                                         (4)(0.2)
                                         (5)(0.22) (6)(0.24) (7)(0.4)
                                         (8)(0.5) (9)(0.57) (10)(0.61) (11)(0.65)
                                         (12)(0.66) (13)(0.67) (14)(0.66) (15)(0.65)
                                         (16)(0.61) (17)(0.57) (18)(0.5)
                                         (19,20) (0.4) (21,22)(0.15)
                                         (23,24)(0.12) ..
EQ-42           =DAY-SCHEDULE            (1)(0.05) (2)(0.05) (3)(0.09)
                                         (4)(0.15)
                                         (5)(0.2) (6)(0.35) (7)(0.4)
                                         (8)(0.5) (9)(0.55) (10)(0.6) (11)(0.7)
                                         (12)(0.72) (13)(0.74) (14)(0.72) (15)(0.7)
                                         (16)(0.6) (17)(0.55) (18)(0.5)
                                         (19) (0.4) (20)(0.3) (21)(0.2)
                                         (22)(0.1) (23)(0.08) (24)(0.05)  ..
EQ-5            =DAY-SCHEDULE            (1)(0.05) (2)(0.05) (3)(0.09)
                                         (4)(0.1)
                                         (5)(0.15) (6)(0.2) (7)(0.22)
                                         (8)(0.27) (9)(0.3) (10)(0.33) (11)(0.35)
                                         (12)(0.38) (13)(0.4) (14)(0.37) (15)(0.35)
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                                    (16)(0.3) (17)(0.28) (18)(0.25)
                                    (19) (0.2) (20)(0.15) (21)(0.1)
                                    (22)(0.08) (23)(0.06) (24)(0.05)  ..

EQ-5A         =DAY-SCHEDULE         (1)(0.062) (2)(0.065) (3)(0.07)
                                    (4)(0.075)
                                    (5)(0.08) (6)(0.081) (7)(0.085)
                                    (8)(0.086) (9)(0.087) (10)(0.09) (11)(0.1)
                                    (12)(0.14) (13)(0.16) (14)(0.14) (15)(0.1)
                                    (16)(0.09) (17)(0.088) (18)(0.08)
                                    (19) (0.075) (20)(0.072) (21)(0.07)
                                    (22)(0.065) (23)(0.062) (24)(0.062)  ..
EQ-6          =DAY-SCHEDULE         (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.1)
                                    (5)(0.15) (6)(0.2) (7)(0.22)
                                    (8)(0.27) (9)(0.3) (10)(0.33) (11)(0.35)
                                    (12)(0.38) (13)(0.4) (14)(0.37) (15)(0.35)
                                    (16)(0.3) (17)(0.28) (18)(0.25)
                                    (19) (0.2) (20)(0.15) (21)(0.1)
                                    (22)(0.08) (23)(0.06) (24)(0.05)  ..
EQ-6A          =DAY-SCHEDULE        (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.1)
                                    (5)(0.15) (6)(0.2) (7)(0.22)
                                    (8)(0.27) (9)(0.36) (10)(0.4) (11)(0.47)
                                    (12)(0.52) (13)(0.55) (14)(0.52) (15)(0.47)
                                    (16)(0.4) (17)(0.36) (18)(0.27)
                                    (19) (0.2) (20)(0.15) (21)(0.1)
                                    (22)(0.08) (23)(0.06) (24)(0.05)  ..
EQ-11          =DAY-SCHEDULE        (1)(0.05) (2)(0.05) (3)(0.09)
                                    (4)(0.15)
                                    (5)(0.2) (6)(0.3) (7)(0.4)
                                    (8)(0.5) (9)(0.8) (10)(0.85) (11)(0.9)
                                    (12)(0.95) (13)(1) (14)(0.95) (15)(0.9)
                                    (16)(0.85) (17)(0.8) (18)(0.7)
                                    (19) (0.5) (20)(0.3) (21)(0.2)
                                    (22)(0.09) (23)(0.08) (24)(0.05)  ..
EQ-11A          =DAY-SCHEDULE       (1)(0.09) (2)(0.1) (3)(0.2)
                                    (4)(0.45)
                                    (5)(0.5) (6)(0.55) (7)(0.8)
                                    (8)(0.88) (9)(0.92) (10)(0.95) (11)(0.97)
                                    (12)(0.99) (13)(1) (14)(0.99) (15)(0.97)
                                    (16)(0.95) (17)(0.92) (18)(0.88)
                                    (19) (0.8) (20)(0.55) (21)(0.5)
                                    (22)(0.45) (23)(0.2) (24)(0.09)  ..
EQ-11B          =DAY-SCHEDULE       (1)(0.09) (2)(0.1) (3)(0.11)
                                    (4)(0.2)
                                    (5)(0.25) (6)(0.35) (7)(0.6)
                                    (8)(0.8) (9)(0.88) (10)(0.9) (11)(0.97)
                                    (12)(1) (13)(1) (14)(1) (15)(0.97)
                                    (16)(0.9) (17)(0.88) (18)(0.8)
                                    (19) (0.66) (20)(0.65) (21)(0.63)
                                    (22)(0.62) (23)(0.61) (24)(0.6)  ..

EQ-WEEK       =WEEK-SCHEDULE        (MON,FRI) EQ-1   (WEH) EQ-2  ..
EQ-WEEKA      =WEEK-SCHEDULE        (WD) EQ-1A (WEH) EQ-2B  ..
EQ-WEEKAA     =WEEK-SCHEDULE        (WD) EQ-1AA (WEH) EQ-2B  ..
EQ-WEEK1      =WEEK-SCHEDULE        (WD) EQ-4 (WEH) EQ-2  ..
EQ-WEEK1A     =WEEK-SCHEDULE        (WD) EQ-4 (WEH) EQ-4  ..
$EQ-WEEK1B    =WEEK-SCHEDULE        (WD) EQ-2B (WEH) EQ-2B  ..
EQ-WEEK2      =WEEK-SCHEDULE        (WD) EQ-5 (WEH) EQ-2  ..
EQ-WEEK2A     =WEEK-SCHEDULE        (WD) EQ-5A (WEH) EQ-2  ..
EQ-WEEK3      =WEEK-SCHEDULE        (WD) EQ-6 (WEH) EQ-2  ..
EQ-WEEK3A     =WEEK-SCHEDULE        (WD) EQ-6A (WEH) EQ-2  ..
EQ-WEEK4      =WEEK-SCHEDULE        (WD) EQ-11 (WEH) EQ-2  ..
EQ-WEEK4A     =WEEK-SCHEDULE        (WD) EQ-11A (WEH) EQ-2A  ..
EQ-WEEK4B     =WEEK-SCHEDULE        (WD) EQ-11B (WEH) EQ-2AA  ..
EQ-WEEK5      =WEEK-SCHEDULE        (WD) EQ-41 (WEH) EQ-21  ..
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EQ-WEEK5A      =WEEK-SCHEDULE      (WD) EQ-41A (WEH) EQ-21  ..
EQ-WEEK7       =WEEK-SCHEDULE      (WD) EQ-42 (WEH) EQ-2  ..

EQUIP-1       =SCHEDULE            THRU JAN 1 EQ-WEEK2A
                                   THRU JAN 3 EQ-WEEK2
                                   THRU JAN 7 EQ-WEEK7
                                   THRU JAN 10 EQ-WEEK3A
                                   THRU JAN 14 EQ-WEEK7
                                   THRU JAN 15 EQ-WEEK2
                                   THRU FEB 7 EQ-WEEK7
                                   THRU FEB 8 EQ-WEEK4
                                   THRU FEB 12 EQ-WEEK7
                                   THRU FEB 15 EQ-WEEK4
                                   THRU FEB 22 EQ-WEEK7
                                   THRU FEB 23 EQ-WEEK3A
                                   THRU FEB 26 EQ-WEEK
                                   THRU MAR 9 EQ-WEEK7
                                   THRU MAR 18 EQ-WEEK2
                                   THRU MAR 31 EQ-WEEK7
                                   THRU APR 12 EQ-WEEK
                                   THRU APR 15 EQ-WEEK3A
                                   THRU APR 18 EQ-WEEK7
                                   THRU APR 23 EQ-WEEK
                                   THRU APR 29 EQ-WEEK7
                                   THRU MAY 25 EQ-WEEK4
                                   THRU MAY 26 EQ-WEEK1A
                                   THRU JUN 8 EQ-WEEK7
                                   THRU JUN 24 EQ-WEEK5
                                   THRU JUL 2 EQ-WEEK3A
                                   THRU JUL 28 EQ-WEEK5A
                                   THRU AUG 10 EQ-WEEKA
                                   THRU AUG 12 EQ-WEEK5A
                                   THRU AUG 15 EQ-WEEKA
                                   THRU SEP 2 EQ-WEEK4A
                                   THRU SEP 3 EQ-WEEK1
                                   THRU SEP 9 EQ-WEEK4A
                                   THRU SEP 17 EQ-WEEK
                                   THRU SEP 19 EQ-WEEKA
                                   THRU SEP 20 EQ-WEEKAA
                                   THRU OCT 5 EQ-WEEK
                                   THRU OCT 8 EQ-WEEK7
                                   THRU OCT 15 EQ-WEEK
                                   THRU OCT 18 EQ-WEEK7
                                   THRU OCT 21 EQ-WEEK
                                   THRU OCT 24 EQ-WEEK4
                                   THRU NOV 2 EQ-WEEK
                                   THRU NOV 3 EQ-WEEK4B
                                   THRU NOV 16 EQ-WEEK4
                                   THRU NOV 20 EQ-WEEK
                                   THRU NOV 25 EQ-WEEK3
                                   THRU NOV 26 EQ-WEEK
                                   THRU DEC 3 EQ-WEEK7
                                   THRU DEC 8 EQ-WEEK4
                                   THRU DEC 20 EQ-WEEK7
                                   THRU DEC 31 EQ-WEEK2A ..


$ INFILTRATION SCHEDULE
INFIL-SCH      =SCHEDULE           THRU DEC 31 (ALL) (1,24) (1) ..


$               SET DEFAULT VALUES
                SET-DEFAULT FOR SPACE  FLOOR-WEIGHT=0  ..
                SET-DEFAULT FOR EXTERIOR-WALL  CONSTRUCTION=WALL-1  ..
                SET-DEFAULT FOR WINDOW GLASS-TYPE=WIND-1    ..
```

```
$               GENERAL SPACE DEFINITION

 OFFICE         =SPACE-CONDITIONS   PEOPLE-SCHEDULE      =OCCUPY-1
                                    NUMBER-OF-PEOPLE     =20
                                    PEOPLE-HEAT-GAIN     =350
                                    LIGHTING-SCHEDULE    =LIGHTS-1
                                    LIGHTING-TYPE        =REC-FLUOR-RV
                                    LIGHT-TO-SPACE       =0.9
                                    LIGHTING-W/SQFT      =1.7
                                    EQUIP-SCHEDULE       =EQUIP-1
                                    EQUIPMENT-W/SQFT     =1.8
                                    INF-METHOD           =AIR-CHANGE
                                    AIR-CHANGES/HR       =0
                                    INF-SCHEDULE         =INFIL-SCH  ..

CLASSROOM       =SPACE-CONDITIONS   PEOPLE-SCHEDULE      =OCCUPY-1
                                    NUMBER-OF-PEOPLE     =50
                                    PEOPLE-HEAT-GAIN     =350
                                    LIGHTING-SCHEDULE    =LIGHTS-1
                                    LIGHTING-TYPE        =REC-FLUOR-RV
                                    LIGHT-TO-SPACE       =0.9
                                    LIGHTING-W/SQFT      =1.7
                                    EQUIP-SCHEDULE       =EQUIP-1
                                    EQUIPMENT-W/SQFT     =1.8
                                    INF-METHOD           =AIR-CHANGE
                                    AIR-CHANGES/HR       =0
                                    INF-SCHEDULE         =INFIL-SCH  ..

GYM            =SPACE-CONDITIONS    PEOPLE-SCHEDULE      =OCCUPY-1
                                    NUMBER-OF-PEOPLE     =50
                                    PEOPLE-HEAT-GAIN     =350

                                    LIGHTING-SCHEDULE    =LIGHTS-1
                                    LIGHTING-TYPE        =INCAND
                                    LIGHT-TO-SPACE       =0.9
                                    LIGHTING-W/SQFT      =1.7

                                    EQUIP-SCHEDULE       =EQUIP-1
                                    EQUIPMENT-W/SQFT     =1.8

                                    INF-METHOD           =AIR-CHANGE
                                    AIR-CHANGES/HR       =0
                                    INF-SCHEDULE         =INFIL-SCH  ..

$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION ONE

PLENUM-1-1       =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                  Z=9
                                                  AREA=2640
                                                  VOLUME=11880 ..

P-1-1    =EXTERIOR-WALL    HEIGHT = 4.5     WIDTH = 88
                           X=0      Y=0     Z=0   AZIMUTH = 180 ..
P-2-1    =EXTERIOR-WALL    HEIGHT = 4.5     WIDTH = 30
                           X=88     Y=0     Z=0   AZIMUTH = 90  ..
P-3-1    =INTERIOR-WALL    HEIGHT = 4.5     WIDTH = 88
                                            NEXT-TO SPACE1-3
                                            CONSTRUCTION = SB-U
                           X=88     Y=30    Z=0   AZIMUTH = 0   ..
P-4-1    =EXTERIOR-WALL    HEIGHT =4.5      WIDTH = 30
                           X=0      Y=30    Z=0   AZIMUTH = 270   ..


$ FIRST FLOOR SPACE 1
```

```
SPACE1-1       =SPACE             SPACE-CONDITIONS = CLASSROOM
                                  AREA = 2640
                                  VOLUME = 11880
                                  NUMBER-OF-PEOPLE = 90 ..

W-1-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 88
                           X=0    Y=0    Z=0   AZIMUTH = 180 ..
W-2-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 30
                           X=88   Y=0    Z=0   AZIMUTH = 90  ..
WIN1-1   =WINDOW           HEIGHT=6      WIDTH=4    Y=3   X=1 ..
W-3-1    =INTERIOR-WALL    HEIGHT = 9    WIDTH = 88
                                         NEXT-TO SPACE1-3
                                         CONSTRUCTION = SB-U
                           X=88   Y=30   Z=0   AZIMUTH = 0   ..
W-4-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 30
                           X=0    Y=30   Z=0   AZIMUTH = 270   ..
WIN1-2   =WINDOW           HEIGHT=6      WIDTH=8    Y=3   X=20 ..


$ CEILING DEFINITION

POLYGON-CLNG1=  POLYGON
(0,0) (88,0) (88,30)
(0,30) ..

C1-1      =INTERIOR-WALL                   AREA=2640
                                           POLYGON=   POLYGON-CLNG1
                                           X=0   Y=0   Z=9   AZIMUTH = 180
                                           TILT=0
                                           NEXT-TO  PLENUM-1-1
                                           CONSTRUCTION=CLNG-1
                                           INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..

$ ROOF DEFINITION

POLYGON-ROOF1=  POLYGON
(0,0) (88,0) (88,30)
(0,30) ..

TOP-1      =ROOF
            POLYGON=   POLYGON-ROOF1
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..


$ FLOOR DEFINITION

MAT-FIC-1 = MATERIAL
            RESISTANCE = 11.11 ..

$ R-FIC VALUE

SOIL-1    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-1    = LAYERS
            MATERIAL = (MAT-FIC-1,SOIL-1,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-1    =CONSTRUCTION       LAYERS=FL-1-1 ..

POLYGON-FLOOR1=  POLYGON
```

```
(0,0) (88,0) (88,30)
(0,30) ..

FL-1      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR1
            AREA = 2640
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.07
            CONSTRUCTION = FLOOR-1   ..

$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION TWO

PLENUM-1-2     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=2640
                                                VOLUME=11880 ..

P-1-2    =EXTERIOR-WALL     HEIGHT = 4.5     WIDTH = 88
                            X=123.5     Y=0  Z=0  AZIMUTH = 180 ..
P-2-2    =EXTERIOR-WALL     HEIGHT = 4.5     WIDTH = 30
                            X=211.5     Y=0  Z=0   AZIMUTH = 90  ..
P-3-2    =INTERIOR-WALL     HEIGHT = 4.5     WIDTH = 88
                            NEXT-TO SPACE1-3
                            CONSTRUCTION = SB-U
                            X=211.5     Y=30  Z=0   AZIMUTH = 0   ..
P-4-2    =EXTERIOR-WALL     HEIGHT =4.5       WIDTH = 30
                            X=123.5     Y=30  Z=0   AZIMUTH = 270   ..


$ FIRST FLOOR SPACE 2

SPACE1-2     =SPACE                 SPACE-CONDITIONS = CLASSROOM
                                    AREA = 2640
                                    VOLUME = 11880
                                    NUMBER-OF-PEOPLE = 90  ..

W-1-2    =EXTERIOR-WALL     HEIGHT = 9      WIDTH = 88
                            X=123.5   Y=0   Z=0   AZIMUTH = 180   ..
W-2-2    =EXTERIOR-WALL     HEIGHT = 9      WIDTH = 30
                            X=211.5   Y=0   Z=0   AZIMUTH = 90  ..
WIN2-1   =WINDOW            HEIGHT=6        WIDTH=8    Y=3   X=1 ..
W-3-2    =INTERIOR-WALL     HEIGHT = 9      WIDTH = 88
                            NEXT-TO SPACE1-3
                            CONSTRUCTION = SB-U
                            X=211.5   Y=30  Z=0   AZIMUTH = 0   ..
W-4-2    =EXTERIOR-WALL     HEIGHT =9       WIDTH = 30
                            X=123.5   Y=30  Z=0   AZIMUTH = 270   ..
WIN2-2   =WINDOW            HEIGHT=6        WIDTH=4    Y=3   X=26 ..


$ CEILING DEFINITION

POLYGON-CLNG2=  POLYGON
(123.5,0) (211.5,0) (211.5,30)
(123.5,30) ..

C1-2      =INTERIOR-WALL                  AREA=2640
                                          POLYGON=   POLYGON-CLNG2
                                          X=0   Y=0   Z=9   AZIMUTH = 180
                                          TILT=0
                                          NEXT-TO  PLENUM-1-2
                                          CONSTRUCTION=CLNG-1
                                          INT-WALL-TYPE=STANDARD ..
```

```
$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..

$ ROOF DEFINITION

POLYGON-ROOF2=  POLYGON
(123.5,0) (211.5,0) (211.5,30)
(123.5,30) ..

TOP-2      =ROOF
            POLYGON=   POLYGON-ROOF2
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..


$ FLOOR DEFINITION

MAT-FIC-2 = MATERIAL
            RESISTANCE = 11.11 ..
$ R-FIC VALUE

SOIL-2    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-2    = LAYERS
            MATERIAL = (MAT-FIC-2,SOIL-2,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-2    =CONSTRUCTION       LAYERS=FL-1-2 ..

POLYGON-FLOOR2=  POLYGON
(123.5,0) (211.5,0) (211.5,30)
(123.5,30) ..

FL-2      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR2
            AREA = 2640
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.07
            CONSTRUCTION = FLOOR-2   ..

$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION THREE


PLENUM-1-3     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=13931
                                                VOLUME=62689.5  ..

P-1-3    =INTERIOR-WALL    HEIGHT = 4.5       WIDTH = 88
                                              NEXT-TO SPACE1-1
                                              CONSTRUCTION = SB-U
                           X=0      Y=30      Z=0    AZIMUTH = 180   ..
P-2-3    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 39.5
                           X=88     Y=30      Z=0   AZIMUTH = 90  ..
P-3-3    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 35.5
                           X=88     Y=69.5    Z=0   AZIMUTH = 180   ..
P-4-3    =EXTERIOR-WALL    HEIGHT = 4.5        WIDTH = 39.5
                           X=123.5  Y=69.5    Z=0   AZIMUTH = 270   ..
P-5-3    =INTERIOR-WALL    HEIGHT = 4.5       WIDTH = 88
                                              NEXT-TO SPACE1-2
                                              CONSTRUCTION = SB-U
```

```
                             X=123.5  Y=30      Z=0   AZIMUTH = 180   ..
P-6-3    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 72.5
                             X=211.5  Y=30      Z=0   AZIMUTH = 90 ..
P-7-3   =INTERIOR-WALL     HEIGHT = 4.5       WIDTH = 30
                                                NEXT-TO SPACE1-5
                                                CONSTRUCTION = SB-U
                             X=211.5  Y=102.5   Z=0    AZIMUTH = 0   ..
P-8-3    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 28
                             X=181.5  Y=102.5   Z=0    AZIMUTH = 0  ..
P-9-3    =INTERIOR-WALL    HEIGHT = 4.5       WIDTH =95.5
                                                NEXT-TO SPACE1-4
                                                CONSTRUCTION = SB-U
                             X=153.5  Y=102.5   Z=0    AZIMUTH = 0  ..
P-10-3    =EXTERIOR-WALL   HEIGHT = 4.5       WIDTH = 28
                             X=58     Y=102.5   Z=0    AZIMUTH = 0 ..
P-11-3    =INTERIOR-WALL    HEIGHT = 4.5      WIDTH =30
                                                NEXT-TO SPACE1-6
                                                CONSTRUCTION = SB-U
                             X=30     Y=102.5   Z=0    AZIMUTH = 0  ..
P-12-3    =INTERIOR-WALL    HEIGHT = 4.5      WIDTH =72.5
                                                NEXT-TO SPACE1-13
                                                CONSTRUCTION = SB-U
                             X=0      Y=102.5   Z=0    AZIMUTH = 270  ..


$ FIRST FLOOR SPACE 3

SPACE1-3       =SPACE                       SPACE-CONDITIONS = CLASSROOM
                                            AREA=13931
                                            VOLUME=125379
                                            DAYLIGHTING=NO
                                            NUMBER-OF-PEOPLE = 150   ..

W-1-3    =INTERIOR-WALL    HEIGHT = 9        WIDTH = 88
                                             NEXT-TO SPACE1-1
                                              CONSTRUCTION = SB-U
                             X=0      Y=30    Z=0  AZIMUTH = 180   ..

W-2-3    =EXTERIOR-WALL    HEIGHT = 9         WIDTH = 39.5
                             X=88     Y=30    Z=0   AZIMUTH = 90  ..
W-3-3    =EXTERIOR-WALL    HEIGHT = 9         WIDTH = 35.5
                             X=88     Y=69.5  Z=0   AZIMUTH = 180   ..

WIN3-1    =WINDOW          HEIGHT=6           WIDTH=4   Y=3   ..
WIN3-2    =WINDOW          HEIGHT=3           WIDTH=9   Y=0  X=6.75  ..
WIN3-3    =WINDOW          HEIGHT=3           WIDTH=9   Y=0  X=20.75  ..
WIN3-4    =WINDOW          HEIGHT=6           WIDTH=4   Y=3  X=31.5  ..

W-4-3    =EXTERIOR-WALL    HEIGHT = 9         WIDTH = 39.5
                             X=123.5  Y=69.5  Z=0   AZIMUTH = 270   ..
W-5-3    =INTERIOR-WALL    HEIGHT = 9         WIDTH = 88
                                              NEXT-TO SPACE1-2
                                              CONSTRUCTION = SB-U
                             X=123.5  Y=30    Z=0   AZIMUTH = 180   ..
W-6-3    =EXTERIOR-WALL    HEIGHT = 9         WIDTH = 72.5
                             X=211.5  Y=30    Z=0   AZIMUTH = 90 ..
WIN3-5   =WINDOW           HEIGHT=6           WIDTH=8    Y=3   X=15 ..

WIN3-6   =WINDOW           HEIGHT=  9         WIDTH=7    Y=0   X=62 ..

W-7-3   =INTERIOR-WALL     HEIGHT = 9         WIDTH = 30
                                              NEXT-TO SPACE1-5
                                              CONSTRUCTION = SB-U
                             X=211.5 Y=102.5  Z=0    AZIMUTH = 0   ..
W-8-3    =EXTERIOR-WALL    HEIGHT = 9         WIDTH = 28
                             X=181.5  Y=102.5 Z=0    AZIMUTH = 0  ..
WIN3-7   =WINDOW           HEIGHT=9           WIDTH=26   Y=0   X=1 ..
```

```
W-9-3    =INTERIOR-WALL    HEIGHT = 9       WIDTH =95.5
                                            NEXT-TO SPACE1-4
                                            CONSTRUCTION = SB-U
                           X=153.5  Y=102.5   Z=0    AZIMUTH = 0  ..
W-10-3    =EXTERIOR-WALL   HEIGHT = 9       WIDTH = 28
                           X=58  Y=102.5    Z=0    AZIMUTH = 0 ..
WIN3-8   =WINDOW          HEIGHT=9          WIDTH=26   Y=0   X=1 ..

W-11-3    =INTERIOR-WALL    HEIGHT = 9      WIDTH =30
                                            NEXT-TO SPACE1-6
                                            CONSTRUCTION = SB-U
                           X=30  Y=102.5    Z=0    AZIMUTH = 0  ..
W-12-3    =INTERIOR-WALL    HEIGHT =9       WIDTH =72.5
                                            NEXT-TO SPACE1-13
                                            CONSTRUCTION = SB-U
                           X=0  Y=102.5     Z=0    AZIMUTH = 270  ..


$ CEILING DEFINITION

POLYGON-CLNG3=  POLYGON
(0,30) (88,30) (88,69.5) (123.5,69.5) (123.5,30)
(211.5,30) (211.5,102.5) (0,102.5) ..

C1-3      =INTERIOR-WALL                   AREA=13931
                                           POLYGON=   POLYGON-CLNG3
                                           X=0   Y=0   Z=9   AZIMUTH = 180
                                           TILT=0
                                           NEXT-TO  PLENUM-1-3
                                           CONSTRUCTION=CLNG-1
                                           INT-WALL-TYPE=STANDARD ..


$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..

$ ROOF DEFINITION

POLYGON-ROOF3=  POLYGON
(0,30) (88,30) (88,69.5) (123.5,69.5) (123.5,30)
(211.5,30) (211.5,102.5) (0,102.5) ..

TOP-3      =ROOF
            POLYGON=   POLYGON-ROOF3
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..

$ FLOOR DEFINITION

MAT-FIC-3 = MATERIAL
            RESISTANCE = 24.54 ..
$ R-FIC VALUE

SOIL-3    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-3    = LAYERS
            MATERIAL = (MAT-FIC-3,SOIL-3,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-3    =CONSTRUCTION       LAYERS=FL-1-3 ..

POLYGON-FLOOR3=  POLYGON
(0,30) (88,30) (88,69.5) (123.5,69.5) (123.5,30)
```

```
(211.5,30) (211.5,102.5) (0,102.5) ..

FL-3      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR3
            AREA = 13931
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.04
            CONSTRUCTION = FLOOR-3   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION FOUR

PLENUM-1-4     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=5968
                                                VOLUME=26856 ..

P-1-4    =INTERIOR-WALL     HEIGHT = 4.5      WIDTH = 95.5
                            NEXT-TO SPACE1-3
                            CONSTRUCTION = SB-U
                            X=58     Y=102.5  Z=0  AZIMUTH = 180 ..
P-2-4    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 62.5
                            X=153.5  Y=102.5  Z=0   AZIMUTH = 90  ..
P-3-4    =INTERIOR-WALL     HEIGHT = 4.5      WIDTH = 95.5
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=153.5   Y=165   Z=0   AZIMUTH = 0  ..
P-4-4    =EXTERIOR-WALL     HEIGHT =4.5       WIDTH = 62.5
                            X=58   Y=165      Z=0   AZIMUTH = 270   ..


$ FIRST FLOOR SPACE 4

SPACE1-4       =SPACE                     SPACE-CONDITIONS = CLASSROOM
                                          AREA=5968
                                          VOLUME=51282
                                          DAYLIGHTING=NO
                                          NUMBER-OF-PEOPLE = 150   ..

W-1-4    =INTERIOR-WALL     HEIGHT = 9         WIDTH = 95.5
                            NEXT-TO SPACE1-3
                            CONSTRUCTION = SB-U
                            X=58     Y=102.5   Z=0  AZIMUTH = 180 ..
W-2-4    =EXTERIOR-WALL     HEIGHT = 9         WIDTH = 62.5
                            X=153.5  Y=102.5   Z=0   AZIMUTH = 90  ..
WIN4-1   =WINDOW            HEIGHT=6           WIDTH=14   Y=3   X=19 ..

WIN4-2   =WINDOW            HEIGHT=6           WIDTH=14   Y=3   X=33 ..

W-3-4    =INTERIOR-WALL     HEIGHT = 9         WIDTH = 95.5
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=153.5   Y=165    Z=0   AZIMUTH = 0  ..
W-4-4    =EXTERIOR-WALL     HEIGHT = 9         WIDTH = 62.5
                            X=58   Y=165       Z=0   AZIMUTH = 270   ..
WIN4-3   =WINDOW            HEIGHT=6           WIDTH=14   Y=3   X=19 ..

WIN4-4   =WINDOW            HEIGHT=6           WIDTH=14   Y=3   X=33 ..


$ CEILING DEFINITION
POLYGON-CLNG4=  POLYGON
(58,102.5) (153.5,102.5)
(153.5,165) (58,165) ..
```

```
C1-4      =INTERIOR-WALL                    AREA=5968
                                            POLYGON=   POLYGON-CLNG4
                                            X=0   Y=0   Z=9   AZIMUTH = 180
                                            TILT=0
                                            NEXT-TO  PLENUM-1-4
                                            CONSTRUCTION=CLNG-1
                                            INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..

$ ROOF DEFINITION

POLYGON-ROOF4=  POLYGON
(58,102.5) (153.5,102.5)
(153.5,165) (58,165) ..

TOP-4      =ROOF
            POLYGON=   POLYGON-ROOF4
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..

$ FLOOR DEFINITION

MAT-FIC-4 = MATERIAL
            RESISTANCE = 20.62 ..
$ R-FIC VALUE

SOIL-4    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-4    = LAYERS
            MATERIAL = (MAT-FIC-4,SOIL-4,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-4    =CONSTRUCTION       LAYERS=FL-1-4 ..

POLYGON-FLOOR4=  POLYGON
(58,102.5) (153.5,102.5)
(153.5,165) (58,165) ..

FL-4      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR4
            AREA = 5968
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.04
            CONSTRUCTION = FLOOR-4   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION FIVE

PLENUM-1-5     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=2437
                                                VOLUME=10966.5 ..
P-1-5    =EXTERIOR-WALL     HEIGHT = 4.5        WIDTH = 39
                            X=181.5   Y=102.5   Z=0  AZIMUTH = 180 ..
P-2-5   =EXTERIOR-WALL      HEIGHT = 4.5        WIDTH = 62.5
                            X=220.5  Y=102.5    Z=0   AZIMUTH = 90  ..
P-3-5    =EXTERIOR-WALL     HEIGHT = 4.5        WIDTH = 39
                            X=220.5   Y=165     Z=0   AZIMUTH = 0  ..
```

```
P-4-5    =EXTERIOR-WALL     HEIGHT =4.5         WIDTH = 62.5
                            X=181.5   Y=165     Z=0   AZIMUTH = 270   ..


$ FIRST FLOOR SPACE 5

SPACE1-5       =SPACE                     SPACE-CONDITIONS = CLASSROOM
                                          AREA=2437
                                          VOLUME=21933
                                          NUMBER-OF-PEOPLE = 60   ..

W-1-5    =EXTERIOR-WALL     HEIGHT = 9         WIDTH = 39
                            X=181.5   Y=102.5  Z=0  AZIMUTH = 180 ..

W-2-5   =EXTERIOR-WALL      HEIGHT = 9         WIDTH = 62.5
                            X=220.5  Y=102.5   Z=0   AZIMUTH = 90  ..

WIN5-1   =WINDOW            HEIGHT=6           WIDTH=4    Y=3   X=2 ..

WIN5-2   =WINDOW            HEIGHT=6           WIDTH=4    Y=3   X=57 ..

W-3-5    =EXTERIOR-WALL     HEIGHT = 9         WIDTH = 39
                            X=220.5   Y=165    Z=0   AZIMUTH = 0  ..
W-4-5    =EXTERIOR-WALL     HEIGHT =9          WIDTH = 62.5
                            X=181.5   Y=165    Z=0   AZIMUTH = 270   ..
WIN5-3   =WINDOW            HEIGHT=6           WIDTH=14   Y=3   X=19 ..

WIN5-4   =WINDOW            HEIGHT=6           WIDTH=14   Y=3   X=33 ..


$ CEILING DEFINITION

POLYGON-CLNG5=  POLYGON
(181.5,102.5) (220.5,102.5)
(220.5,165) (181.5,165) ..

C1-5      =INTERIOR-WALL                   AREA=2437
                                           POLYGON=   POLYGON-CLNG5
                                           X=0   Y=0   Z=9   AZIMUTH = 180
                                           TILT=0
                                           NEXT-TO  PLENUM-1-5
                                           CONSTRUCTION=CLNG-1
                                           INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..

$ ROOF DEFINITION

POLYGON-ROOF5=  POLYGON
(181.5,102.5) (220.5,102.5)
(220.5,165) (181.5,165) ..

TOP-5      =ROOF
            POLYGON=   POLYGON-ROOF5
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..

$ FLOOR DEFINITION

MAT-FIC-5 = MATERIAL
            RESISTANCE = 12.17 ..
$ R-FIC VALUE

SOIL-5    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
```

```
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-5    = LAYERS
            MATERIAL = (MAT-FIC-5,SOIL-5,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-5    =CONSTRUCTION       LAYERS=FL-1-5 ..

POLYGON-FLOOR5=  POLYGON
(181.5,102.5) (220.5,102.5)
(220.5,165) (181.5,165) ..

FL-5      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR5
            AREA = 2437
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.06
            CONSTRUCTION = FLOOR-5   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION SIX

PLENUM-1-6     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=15806
                                                VOLUME=71127 ..

P-1-6    =INTERIOR-WALL     HEIGHT = 4.5        WIDTH = 30
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=0   Y=102.5       Z=0  AZIMUTH = 180 ..
P-2-6   =EXTERIOR-WALL      HEIGHT = 4.5        WIDTH = 62.5
                            X=30  Y=102.5       Z=0   AZIMUTH = 90  ..
P-3-6    =EXTERIOR-WALL     HEIGHT = 4.5        WIDTH = 28
                            X=30   Y=165        Z=0   AZIMUTH = 180  ..
P-4-6    =INTERIOR-WALL     HEIGHT =4.5         WIDTH = 95.5
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=58   Y=165        Z=0   AZIMUTH = 180  ..
P-5-6   =EXTERIOR-WALL      HEIGHT = 4.5        WIDTH = 28
                            X=153.5  Y=165      Z=0   AZIMUTH = 180 ..
P-6-6    =INTERIOR-WALL     HEIGHT = 4.5        WIDTH = 30
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=181.5   Y=165   Z=0   AZIMUTH = 180  ..
P-7-6   =EXTERIOR-WALL      HEIGHT = 4.5      WIDTH = 72.5
                            X=211.5  Y=165    Z=0   AZIMUTH = 90 ..
P-8-6    =INTERIOR-WALL     HEIGHT = 4.5      WIDTH = 88
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=211.5  Y=237.5  Z=0  AZIMUTH =0  ..
P-9-6    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 39.5
                            X=123.5  Y=237.5  Z=0  AZIMUTH =270  ..
P-10-6   =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 35.5
                            X=123.5  Y=198    Z=0   AZIMUTH = 0 ..
P-11-6   =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 39.5
                            X=88  Y=198       Z=0   AZIMUTH = 90 ..
P-12-6    =INTERIOR-WALL    HEIGHT = 4.5      WIDTH = 88
                            NEXT-TO SPACE1-6
                            CONSTRUCTION = SB-U
                            X=88  Y=237.5     Z=0  AZIMUTH =0  ..
P-13-6   =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 135
                            X=0  Y=237.5      Z=0   AZIMUTH = 270 ..
```

```
$ FIRST FLOOR SPACE 6  $$$$$$$$$$$$$$

SPACE1-6       =SPACE                    SPACE-CONDITIONS = CLASSROOM
                                         AREA=15806
                                         VOLUME=142254
                                         DAYLIGHTING=NO
                                         NUMBER-OF-PEOPLE = 250   ..

W-1-6    =INTERIOR-WALL     HEIGHT = 9     WIDTH = 30
                            NEXT-TO SPACE1-3
                            CONSTRUCTION = SB-U
                            X=0   Y=102.5   Z=0  AZIMUTH = 180 ..
W-2-6    =EXTERIOR-WALL     HEIGHT = 9      WIDTH = 62.5
                            X=30  Y=102.5   Z=0   AZIMUTH = 90  ..
WIN6-10   =WINDOW           HEIGHT=6        WIDTH=14   Y=3   X=19 ..

WIN6-11   =WINDOW           HEIGHT=6        WIDTH=14   Y=3   X=33 ..

W-3-6    =EXTERIOR-WALL     HEIGHT = 9      WIDTH = 28
                            X=30   Y=165    Z=0   AZIMUTH = 180  ..
WIN6-9   =WINDOW            HEIGHT=9        WIDTH=26   Y=0   X=1 ..

W-4-6    =INTERIOR-WALL     HEIGHT =9       WIDTH = 95.5
                            NEXT-TO SPACE1-4
                            CONSTRUCTION = SB-U
                            X=58   Y=165    Z=0   AZIMUTH = 180  ..

W-5-6   =EXTERIOR-WALL      HEIGHT = 9      WIDTH = 28
                            X=153.5  Y=165  Z=0   AZIMUTH = 180 ..
WIN6-8   =WINDOW            HEIGHT=9        WIDTH=26   Y=0   X=1 ..

W-6-6    =INTERIOR-WALL     HEIGHT = 9      WIDTH = 30
                            NEXT-TO SPACE1-5
                            CONSTRUCTION = SB-U
                            X=181.5   Y=165  Z=0   AZIMUTH = 180  ..
W-7-6   =EXTERIOR-WALL      HEIGHT = 9       WIDTH = 72.5
                            X=211.5  Y=165   Z=0   AZIMUTH = 90 ..
WIN6-1   =WINDOW            HEIGHT=9         WIDTH=7    Y=0   X=1 ..

WIN6-2   =WINDOW            HEIGHT=6         WIDTH=4    Y=3   X=33 ..

WIN6-3   =WINDOW            HEIGHT=6         WIDTH=4    Y=3   X=61 ..

W-8-6    =INTERIOR-WALL     HEIGHT = 9       WIDTH = 88
                            NEXT-TO SPACE1-7
                            CONSTRUCTION = SB-U
                            X=211.5  Y=237.5  Z=0  AZIMUTH =0  ..
W-9-6    =EXTERIOR-WALL     HEIGHT = 9        WIDTH = 39.5
                            X=123.5  Y=237.5  Z=0  AZIMUTH =270  ..
W-10-6   =EXTERIOR-WALL     HEIGHT = 9        WIDTH = 35.5
                            X=123.5  Y=198    Z=0   AZIMUTH = 0 ..
WIN6-4    =WINDOW           HEIGHT=6          WIDTH=4   Y=3   ..

WIN6-5    =WINDOW           HEIGHT=3          WIDTH=9   X=6.75  ..

WIN6-6    =WINDOW           HEIGHT=3          WIDTH=9   X=20.75  ..

WIN6-7    =WINDOW           HEIGHT=6          WIDTH=4   Y=3 X=31.5  ..

W-11-6   =EXTERIOR-WALL     HEIGHT = 9        WIDTH = 39.5
                            X=88  Y=198       Z=0   AZIMUTH = 90 ..
W-12-6    =INTERIOR-WALL    HEIGHT = 9        WIDTH = 88
                            NEXT-TO SPACE1-8
                            CONSTRUCTION = SB-U
                            X=88  Y=237.5     Z=0  AZIMUTH =0  ..
```

```
W-13-6   =EXTERIOR-WALL     HEIGHT = 9     WIDTH = 135
                            X=0  Y=237.5      Z=0   AZIMUTH = 270 ..


$ CEILING DEFINITION


POLYGON-CLNG6=  POLYGON
(0,102.5) (30,102.5) (30,165) (58,165)
(153.5,165) (181.5,165) (211.5,165)
(211.5,237.5) (123.5,237.5) (123.5,198)
(88,198) (88,237.5) (0,237.5) ..


C1-6      =INTERIOR-WALL                   AREA=15806
                                           POLYGON=   POLYGON-CLNG6
                                           X=0   Y=0   Z=9   AZIMUTH = 180
                                           TILT=0
                                           NEXT-TO  PLENUM-1-6
                                           CONSTRUCTION=CLNG-1
                                           INT-WALL-TYPE=STANDARD ..


$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..



$ ROOF DEFINITION

POLYGON-ROOF6=  POLYGON
(0,102.5) (30,102.5) (30,165) (58,165)
(153.5,165) (181.5,165) (211.5,165)
(211.5,237.5) (123.5,237.5) (123.5,198)
(88,198) (88,237.5) (0,237.5) ..

TOP-6      =ROOF
            POLYGON=   POLYGON-ROOF6
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..


$ FLOOR DEFINITION

MAT-FIC-6 = MATERIAL
            RESISTANCE = 22.18 ..
$ R-FIC VALUE

SOIL-6    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-6    = LAYERS
            MATERIAL = (MAT-FIC-6,SOIL-6,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-6    =CONSTRUCTION       LAYERS=FL-1-6 ..

POLYGON-FLOOR6=  POLYGON
(0,102.5) (30,102.5) (30,165) (58,165)
(153.5,165) (181.5,165) (211.5,165)
(211.5,237.5) (123.5,237.5) (123.5,198)
(88,198) (88,237.5) (0,237.5) ..

FL-6      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR6
```

```
            AREA = 15806
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.04
            CONSTRUCTION = FLOOR-6   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION SEVEN

PLENUM-1-7     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=2640
                                                VOLUME=11880 ..
P-1-7    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 30
                            X=211.5  Y=237.5  Z=0  AZIMUTH = 90 ..
P-2-7   =EXTERIOR-WALL      HEIGHT = 4.5      WIDTH = 88
                            X=211.5 Y=267.5   Z=0  AZIMUTH = 0 ..
P-3-7    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 30
                            X=123.5  Y=267.5  Z=0  AZIMUTH = 270 ..


$ FIRST FLOOR SPACE 7

SPACE1-7      =SPACE                      SPACE-CONDITIONS = CLASSROOM
                                          AREA=2640
                                          VOLUME=23760
                                          NUMBER-OF-PEOPLE = 90  ..

W-1-7    =EXTERIOR-WALL     HEIGHT = 9        WIDTH = 30
                            X=211.5  Y=237.5  Z=0  AZIMUTH = 90 ..
WIN7-1  =WINDOW             HEIGHT=6          WIDTH=8    Y=3   X=20 ..

W-2-7   =EXTERIOR-WALL      HEIGHT = 9        WIDTH = 88
                            X=211.5 Y=267.5   Z=0  AZIMUTH = 0 ..
W-3-7    =EXTERIOR-WALL     HEIGHT = 9        WIDTH = 30
                            X=123.5  Y=267.5  Z=0  AZIMUTH = 270 ..
WIN7-2  =WINDOW             HEIGHT=6          WIDTH=4    Y=3   X=1 ..


$ CEILING DEFINITION

POLYGON-CLNG7=  POLYGON
(123.5,237.5) (211.5,237.5)
(211.5,267.5) (123.5,267.5) ..

C1-7      =INTERIOR-WALL                   AREA=15806
                                           POLYGON=   POLYGON-CLNG7
                                           X=0   Y=0   Z=9   AZIMUTH = 180
                                           TILT=0
                                           NEXT-TO  PLENUM-1-7
                                           CONSTRUCTION=CLNG-1
                                           INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..


$ ROOF DEFINITION

POLYGON-ROOF7=  POLYGON
(123.5,237.5) (211.5,237.5)
(211.5,267.5) (123.5,267.5) ..

TOP-7      =ROOF
            POLYGON=   POLYGON-ROOF7
            X=0   Y=0   Z=13.5
```

```
             AZIMUTH = 180
             TILT=0  GND-REFLECTANCE=0
             CONSTRUCTION = ROOF-1 ..

$ FLOOR DEFINITION

MAT-FIC-7 = MATERIAL
             RESISTANCE = 11.11 ..
$ R-FIC VALUE

SOIL-7    = MATERIAL
             THICKNESS = 1.0 CONDUCTIVITY = 1.0
             DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-7    = LAYERS
             MATERIAL = (MAT-FIC-7,SOIL-7,CC03,LT01)
             I-F-R = 0.77 ..

FLOOR-7    =CONSTRUCTION       LAYERS=FL-1-7 ..

POLYGON-FLOOR7=  POLYGON
(123.5,237.5) (211.5,237.5)
(211.5,267.5) (123.5,267.5) ..

FL-7      = UNDERGROUND-FLOOR
             POLYGON=   POLYGON-FLOOR7
             AREA = 15806
             X=0   Y=0   Z=0
             AZIMUTH = 180
             TILT=0
             U-EFFECTIVE = 0.07
             CONSTRUCTION = FLOOR-7   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION EIGHT

PLENUM-1-8     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=2640
                                                VOLUME=11880 ..
P-1-8    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 30
                            X=88  Y=237.5     Z=0  AZIMUTH = 90 ..
P-2-8    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 88
                            X=88  Y=267.5     Z=0  AZIMUTH = 0 ..
P-3-8    =EXTERIOR-WALL     HEIGHT = 4.5      WIDTH = 30
                            X=0  Y=267.5      Z=0  AZIMUTH = 270 ..

$ FIRST FLOOR SPACE 8

SPACE1-8      =SPACE                      SPACE-CONDITIONS = CLASSROOM
                                          AREA=2640
                                          VOLUME=23760
                                          NUMBER-OF-PEOPLE = 90  ..

W-1-8    =EXTERIOR-WALL     HEIGHT = 9      WIDTH = 30
                            X=88  Y=237.5   Z=0  AZIMUTH = 90 ..
WIN8-1    =WINDOW           HEIGHT=6        WIDTH=4   Y=3   X=25 ..

W-2-8   =EXTERIOR-WALL      HEIGHT = 9      WIDTH = 88
                            X=88 Y=267.5    Z=0  AZIMUTH = 0 ..
W-3-8    =EXTERIOR-WALL     HEIGHT = 9      WIDTH = 30
                            X=0  Y=267.5    Z=0  AZIMUTH = 270 ..
WIN8-2    =WINDOW           HEIGHT=6        WIDTH=8   Y=3   X=1 ..


$ CEILING DEFINITION
```

```
POLYGON-CLNG8=  POLYGON
(0,237.5) (88,237.5)
(88,267.5) (0,267.5) ..

C1-8      =INTERIOR-WALL                  AREA=2640
                                          POLYGON=   POLYGON-CLNG8
                                          X=0   Y=0   Z=9   AZIMUTH = 180
                                          TILT=0
                                          NEXT-TO  PLENUM-1-8
                                          CONSTRUCTION=CLNG-1
                                          INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..


$ ROOF DEFINITION

POLYGON-ROOF8=  POLYGON
(0,237.5) (88,237.5)
(88,267.5) (0,267.5) ..

TOP-8      =ROOF
            POLYGON=   POLYGON-ROOF8
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..

$ FLOOR DEFINITION

MAT-FIC-8 = MATERIAL
            RESISTANCE = 11.11 ..
$ R-FIC VALUE

SOIL-8    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-8    = LAYERS
            MATERIAL = (MAT-FIC-8,SOIL-8,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-8    =CONSTRUCTION       LAYERS=FL-1-8 ..

POLYGON-FLOOR8=  POLYGON
(0,237.5) (88,237.5)
(88,267.5) (0,267.5) ..

FL-8      = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR8
            AREA =2640
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.07
            CONSTRUCTION = FLOOR-8   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION NINE


PLENUM-1-9     =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                Z=9
                                                AREA=8347
                                                VOLUME=37561.5  ..
```

```
P-1-9    =INTERIOR-WALL    HEIGHT = 4.5       WIDTH = 38
                                              NEXT-TO SPACE1-3
                                              CONSTRUCTION = SB-U
                           X=-15   Y=57.5     Z=0   AZIMUTH = 90   ..
P-2-9   =INTERIOR-WALL     HEIGHT = 4.5       WIDTH = 166
                                              NEXT-TO SPACE1-3
                                              CONSTRUCTION = SB-U
                           X=-15     Y=95.5   Z=0   AZIMUTH = 0  ..
P-3-9    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 67
                           X=-181  Y=95.5     Z=0   AZIMUTH = 270   ..
P-4-9    =EXTERIOR-WALL    HEIGHT =4.5        WIDTH = 32
                           X=-181   Y=28.5    Z=0   AZIMUTH = 180   ..
P-5-9    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 5.5
                           X=-149   Y=28.5    Z=0   AZIMUTH = 270   ..
P-6-9    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 65
                           X=-149   Y=23      Z=0   AZIMUTH = 180 ..
P-7-9   =EXTERIOR-WALL     HEIGHT = 4.5       WIDTH = 63.5
                           X=-84   Y=23       Z=0    AZIMUTH = 90   ..
P-8-9    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 39
                           X=-84   Y=86.5     Z=0    AZIMUTH = 180   ..
P-9-9    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH =29
                           X=-45  Y=86.5      Z=0    AZIMUTH = 270  ..
P-10-9   =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 30
                           X=-45  Y=57.5      Z=0    AZIMUTH = 180 ..


$ FIRST FLOOR SPACE 9

SPACE1-9       =SPACE                     SPACE-CONDITIONS = CLASSROOM
                                          AREA = 8347
                                          VOLUME = 75123
                                          DAYLIGHTING=NO
                                          NUMBER-OF-PEOPLE = 100   ..

W-1-9    =INTERIOR-WALL   HEIGHT = 9         WIDTH = 38
                                             NEXT-TO SPACE1-3
                                             CONSTRUCTION = SB-U
                          X=-15    Y=57.5    Z=0   AZIMUTH = 90   ..
W-2-9    =INTERIOR-WALL   HEIGHT = 9         WIDTH = 166
                                             NEXT-TO SPACE1-3
                                             CONSTRUCTION = SB-U
                          X=-15     Y=95.5   Z=0   AZIMUTH = 0  ..
W-3-9    =EXTERIOR-WALL   HEIGHT = 9         WIDTH = 67
                          X=-181  Y=95.5     Z=0   AZIMUTH = 270   ..
WIN9-1   =WINDOW          HEIGHT=6           WIDTH=4   Y=3   X=33 ..

WIN9-2   =WINDOW          HEIGHT=6           WIDTH=4   Y=3   X=62 ..

WIN9-3   =WINDOW          HEIGHT=9           WIDTH=7   Y=0   X=0 ..

W-4-9    =EXTERIOR-WALL   HEIGHT =9          WIDTH = 32
                          X=-181   Y=28.5    Z=0   AZIMUTH = 180   ..
W-5-9    =EXTERIOR-WALL   HEIGHT = 9         WIDTH = 5.5
                          X=-149   Y=28.5    Z=0   AZIMUTH = 270   ..
WIN9-4   =WINDOW          HEIGHT=6           WIDTH=4   Y=3   X=0 ..

W-6-9    =EXTERIOR-WALL   HEIGHT = 9         WIDTH = 65
                          X=-149   Y=23  Z=0   AZIMUTH = 180 ..
W-7-9   =EXTERIOR-WALL    HEIGHT = 9         WIDTH = 63.5
                          X=-84   Y=23  Z=0  AZIMUTH = 90   ..
W-8-9    =EXTERIOR-WALL   HEIGHT = 9         WIDTH = 39
                          X=-84   Y=86.5     Z=0    AZIMUTH = 180   ..
WIN9-5   =WINDOW          HEIGHT=8           WIDTH=38       X=0.5 ..

W-9-9    =EXTERIOR-WALL   HEIGHT = 9        WIDTH =29
                          X=-45  Y=86.5     Z=0    AZIMUTH = 270  ..
W-10-9    =EXTERIOR-WALL  HEIGHT = 9        WIDTH = 30
```

```
                X=-45  Y=57.5     Z=0    AZIMUTH = 180 ..

$ CEILING DEFINITION

POLYGON-CLNG9=  POLYGON
(-15,57.5) (-15,95.5) (-181,95.5)
(-181,28.5) (-149,28.5) (-149,23)
(-84,23) (-84,86.5) (-45,86.5)
(-45,57.5)  ..

C1-9      =INTERIOR-WALL                    AREA=8347
                                            POLYGON=   POLYGON-CLNG3
                                            X=0   Y=0   Z=9   AZIMUTH = 180
                                            TILT=0
                                            NEXT-TO  PLENUM-1-9
                                            CONSTRUCTION=CLNG-1
                                            INT-WALL-TYPE=STANDARD ..

$ ROOF DEFINITION

POLYGON-ROOF9=  POLYGON
(-15,57.5) (-15,95.5) (-181,95.5)
(-181,28.5) (-149,28.5) (-149,23)
(-84,23) (-84,86.5) (-45,86.5)
(-45,57.5)  ..

TOP-9      =ROOF
            POLYGON=   POLYGON-ROOF9
            X=0   Y=0   Z=13.5   AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1   ..

$ FLOOR DEFINITION

MAT-FIC-9 = MATERIAL
            RESISTANCE = 16.24 ..
$ R-FIC VALUE

SOIL-9    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-9    = LAYERS
            MATERIAL = (MAT-FIC-9,SOIL-9,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-9    =CONSTRUCTION       LAYERS=FL-1-9 ..

POLYGON-FLOOR9=  POLYGON

(-15,57.5) (-15,95.5) (-181,95.5)
(-181,28.5) (-149,28.5) (-149,23)
(-84,23) (-84,86.5) (-45,86.5)
(-45,57.5)  ..

FL-9      =UNDERGROUND-FLOOR
           POLYGON=   POLYGON-FLOOR9
           AREA = 8347
           X=0   Y=0   Z=0
           AZIMUTH = 180
           TILT=0
           U-EFFECTIVE = 0.05
           CONSTRUCTION = FLOOR-9   ..
```

```
$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION TEN


PLENUM-1-10      =SPACE      ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                                 Z=9
                                                 AREA=6084
                                                 VOLUME=27378 ..

P-1-10    =INTERIOR-WALL   HEIGHT = 4.5        WIDTH = 36
                                               NEXT-TO SPACE1-4
                                               CONSTRUCTION = SB-U
                           X=-15   Y=158       Z=0   AZIMUTH = 90   ..
P-2-10    =EXTERIOR-WALL   HEIGHT = 4.5        WIDTH = 169
                           X=-15  Y=194        Z=0   AZIMUTH = 0   ..
P-3-10    =EXTERIOR-WALL   HEIGHT =4.5         WIDTH = 36
                           X=-184   Y=194      Z=0  AZIMUTH = 270   ..
P-4-10    =INTERIOR-WALL   HEIGHT = 4.5        WIDTH = 169
                                               NEXT-TO SPACE1-4
                                               CONSTRUCTION = SB-U
                           X=-184     Y=158    Z=0   AZIMUTH = 180  ..


$ FIRST FLOOR SPACE 10

SPACE1-10      =SPACE                        SPACE-CONDITIONS = CLASSROOM
                                             AREA = 6084
                                             VOLUME = 54756
                                             DAYLIGHTING=NO
                                             NUMBER-OF-PEOPLE = 100   ..

W-1-10    =INTERIOR-WALL    HEIGHT = 9       WIDTH = 36
                                             NEXT-TO SPACE1-4
                                             CONSTRUCTION = SB-U
                            X=-15    Y=158   Z=0 AZIMUTH = 90   ..
W-2-10    =EXTERIOR-WALL    HEIGHT = 9       WIDTH = 169
                            X=-15  Y=194     Z=0   AZIMUTH = 0   ..
W-3-10   =EXTERIOR-WALL     HEIGHT =9        WIDTH = 36
                            X=-184   Y=194   Z=0   AZIMUTH = 270   ..
WIN10-1   =WINDOW           HEIGHT=9         WIDTH=7    X=28  Y=0 ..

W-4-10    =INTERIOR-WALL    HEIGHT = 9       WIDTH = 169
                                             NEXT-TO SPACE1-4
                                             CONSTRUCTION = SB-U
                           X=-184     Y=158  Z=0   AZIMUTH = 180  ..


$ CEILING DEFINITION

POLYGON-CLNG10=  POLYGON
(-15,158) (-15,194) (-184,194)
(-184,158)   ..

C1-10      =INTERIOR-WALL                  AREA=6084
                                           POLYGON=   POLYGON-CLNG10
                                           X=0   Y=0   Z=9   AZIMUTH = 180
                                           TILT=0
                                           NEXT-TO  PLENUM-1-10
                                           CONSTRUCTION=CLNG-1
                                           INT-WALL-TYPE=STANDARD ..

$  ROOF DEFINITION

POLYGON-ROOF10=  POLYGON
(-15,158) (-15,194) (-184,194)
(-184,158)   ..
```

```
TOP-10      =ROOF
            POLYGON=   POLYGON-ROOF10
            X=0   Y=0   Z=13.5   AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1   ..

$ FLOOR DEFINITION

MAT-FIC-10 = MATERIAL
            RESISTANCE = 15.85 ..
$ R-FIC VALUE

SOIL-10    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-10    = LAYERS
            MATERIAL = (MAT-FIC-10,SOIL-10,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-00    =CONSTRUCTION       LAYERS=FL-1-10 ..

POLYGON-FLOOR10=  POLYGON
(-15,158) (-15,194) (-184,194)
(-184,158)   ..

FL-10      =UNDERGROUND-FLOOR
           POLYGON=   POLYGON-FLOOR10
           AREA = 6084
           X=0   Y=0   Z=0
           AZIMUTH = 180
           TILT=0
           U-EFFECTIVE = 0.05
           CONSTRUCTION = FLOOR-00   ..

$ SPECIFIC SPACE DETAILS
$  FIRST FLOOR PLENUM DEFINITION 11


 PLENUM-1-11    =SPACE       ZONE-TYPE=PLENUM  FLOOR-WEIGHT=5
                                               Z=9
                                               AREA=1812
                                               VOLUME=8154 ..

P-1-11    =INTERIOR-WALL   HEIGHT = 4.5       WIDTH = 62.5
                                              NEXT-TO SPACE1-11
                                              CONSTRUCTION = SB-U
                          X=-15     Y=95.5    Z=0   AZIMUTH = 90  ..


$ FIRST FLOOR SPACE 11

SPACE1-11      =SPACE                    SPACE-CONDITIONS = CLASSROOM
                                         AREA = 1812
                                         VOLUME = 16308
                                         DAYLIGHTING=NO
                                         NUMBER-OF-PEOPLE = 100   ..

W-1-11    =INTERIOR-WALL   HEIGHT = 9         WIDTH = 62.5
                                              NEXT-TO SPACE1-5
                                              CONSTRUCTION = SB-U
                          X=-15     Y=95.5    Z=0   AZIMUTH = 90  ..


$ CEILING DEFINITION
```

```
POLYGON-CLNG11=  POLYGON
(-15,95.5) (-15,158) (-44,158)
(-44,95.5)   ..

C1-11      =INTERIOR-WALL                   AREA=1812
                                            POLYGON=   POLYGON-CLNG11
                                            X=0   Y=0   Z=9   AZIMUTH = 180
                                            TILT=0
                                            NEXT-TO  PLENUM-1-11
                                            CONSTRUCTION=CLNG-1
                                            INT-WALL-TYPE=STANDARD ..

$  ROOF DEFINITION

POLYGON-ROOF11=  POLYGON
(-15,95.5) (-15,158) (-44,158)
(-44,95.5)   ..

TOP-11     =ROOF
           POLYGON=   POLYGON-ROOF11
           X=0   Y=0   Z=13.5   AZIMUTH = 180
           TILT=0  GND-REFLECTANCE=0
           CONSTRUCTION = ROOF-1   ..

$ FLOOR DEFINITION

MAT-FIC-11 = MATERIAL
            RESISTANCE = 9.44 ..
$ R-FIC VALUE

SOIL-11    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-11    = LAYERS
            MATERIAL = (MAT-FIC-11,SOIL-11,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-01    =CONSTRUCTION       LAYERS=FL-1-11 ..

POLYGON-FLOOR11=  POLYGON
(-15,95.5) (-15,158) (-44,158)
(-44,95.5)   ..

FL-11      =UNDERGROUND-FLOOR
           POLYGON=   POLYGON-FLOOR11
           AREA = 1812
           X=0   Y=0   Z=0
           AZIMUTH = 180
           TILT=0
           U-EFFECTIVE = 0.08
           CONSTRUCTION = FLOOR-01   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR PLENUM DEFINITION 12

PLENUM-1-12   =SPACE       ZONE-TYPE=PLENUM    FLOOR-WEIGHT=5
                                               Z=23.5
                                               AREA=11562
                                               VOLUME=52029 ..

P-1-12    =EXTERIOR-WALL   HEIGHT = 4.5        WIDTH = 62.5
                           X=-44   Y=95.5      Z=0   AZIMUTH = 90   ..
P-2-12    =EXTERIOR-WALL   HEIGHT = 4.5        WIDTH = 185
                           X=-44  Y=158  Z=0   AZIMUTH = 0   ..
P-3-12    =EXTERIOR-WALL   HEIGHT =4.5         WIDTH = 62.5
```

```
                          X=-229   Y=158      Z=0   AZIMUTH = 270   ..
P-4-12   =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 185
                          X=-229     Y=95.5   Z=0   AZIMUTH = 180  ..


$  FIRST FLOOR SPACE 12  $$$$$$$$$

SPACE1-12       =SPACE                       SPACE-CONDITIONS = GYM
                                             AREA = 11562
                                             VOLUME = 271707
                                             DAYLIGHTING=NO
                                             NUMBER-OF-PEOPLE = 200   ..

W-1-12    =EXTERIOR-WALL   HEIGHT = 23.5      WIDTH = 62.5
                          X=-44    Y=95.5     Z=0   AZIMUTH = 90   ..
W-2-12    =EXTERIOR-WALL   HEIGHT = 23.5      WIDTH = 185
                          X=-44  Y=158  Z=0   AZIMUTH = 0   ..
WIN12-1   =WINDOW          HEIGHT=9           WIDTH=7          X=170 ..

WIN12-2   =WINDOW          HEIGHT=4           WIDTH=72   Y=19   X=55 ..

W-3-12    =EXTERIOR-WALL   HEIGHT =23.5       WIDTH = 62.5
                          X=-229   Y=158      Z=0   AZIMUTH = 270   ..
W-4-12   =EXTERIOR-WALL    HEIGHT = 23.5      WIDTH = 185
                          X=-229     Y=95.5   Z=0   AZIMUTH = 180  ..
WIN12-3   =WINDOW          HEIGHT=9           WIDTH=7          X=4 ..

WIN12-4   =WINDOW          HEIGHT=4           WIDTH=72   Y=19   X=55 ..


$ CEILING DEFINITION


POLYGON-CLNG12=  POLYGON
(-44,95.5) (-44,158) (-229,158)
(-229,95.5)   ..

C1-12      =INTERIOR-WALL                   AREA=11562
                                            POLYGON=   POLYGON-CLNG12
                                            X=0   Y=0   Z=23.5   AZIMUTH = 180
                                            TILT=0
                                            NEXT-TO  PLENUM-1-12
                                            CONSTRUCTION=CLNG-1
                                            INT-WALL-TYPE=STANDARD ..

$ ROOF DEFINITION

POLYGON-ROOF12=  POLYGON
(-44,95.5) (-44,158) (-229,158)
(-229,95.5)   ..

TOP-12    =ROOF
           POLYGON=   POLYGON-ROOF12
           X=0   Y=0   Z=28   AZIMUTH = 180
           TILT=0  GND-REFLECTANCE=0
           CONSTRUCTION = ROOF-1   ..

$ FLOOR DEFINITION

MAT-FIC-12 = MATERIAL
            RESISTANCE = 26.92 ..
$ R-FIC VALUE

SOIL-12    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..
```

```
FL-1-12    = LAYERS
            MATERIAL = (MAT-FIC-12,SOIL-12,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-02    =CONSTRUCTION       LAYERS=FL-1-12 ..

POLYGON-FLOOR12=  POLYGON
(-44,95.5) (-44,158) (-229,158)
(-229,95.5)   ..

FL-12      =UNDERGROUND-FLOOR
           POLYGON=   POLYGON-FLOOR12
           AREA = 11562
           X=0   Y=0   Z=0
           AZIMUTH = 180
           TILT=0
           U-EFFECTIVE = 0.03
           CONSTRUCTION = FLOOR-02   ..


$ SPECIFIC SPACE DETAILS
$ FIRST FLOOR SPACE 13



SPACE1-13     =SPACE                  SPACE-CONDITIONS = OFFICE
                                      AREA = 500
                                      VOLUME = 6500
                                      DAYLIGHTING=NO
                                      NUMBER-OF-PEOPLE = 50   ..

W-1-13    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 136.5
                            X=-15   Y=194      Z=13.5   AZIMUTH = 270   ..
W-1-13R   =ROOF             HEIGHT = 11        WIDTH = 136.5
                                               TILT=45
                            X=-15    Y=194     Z=17.5   AZIMUTH = 270   ..
W-2-13    =EXTERIOR-WALL    HEIGHT = 4.5       WIDTH = 136.5
                            X=0  Y=57.5        Z=13.5   AZIMUTH = 90   ..
W-2-13A   =INTERIOR-WALL    HEIGHT = 13.5      WIDTH = 136.5
                            CONSTRUCTION = SB-U
                            NEXT-TO SPACE1-7
                            X=0  Y=57.5        Z=0   AZIMUTH = 90   ..
W-2-13B    =EXTERIOR-WALL   HEIGHT = 13.5      WIDTH = 57.5
                            X=0  Y=57.5  Z=0   AZIMUTH = 270   ..
WIN13-2    =WINDOW          HEIGHT=6           WIDTH=8    Y=3   X=48 ..

W-2-13C    =EXTERIOR-WALL   HEIGHT = 13.5      WIDTH = 60.5
                            X=0  Y=253.5       Z=0      AZIMUTH = 270   ..
WIN13-1   =WINDOW           HEIGHT=6           WIDTH=8   Y=3   X=47 ..

W-2-13D    =EXTERIOR-WALL   HEIGHT = 17.25     WIDTH = 15
                            X=-15  Y=69.5      Z=0      AZIMUTH = 180   ..
WIN13-4    =WINDOW          HEIGHT=9           WIDTH=14    Y=0   X=0.5 ..

W-2-13E    =EXTERIOR-WALL   HEIGHT = 17.25     WIDTH = 15
                            X=0  Y=186 Z=0     AZIMUTH = 0   ..
WIN13-3    =WINDOW          HEIGHT=9           WIDTH=14    Y=0   X=0.5 ..

W-2-13R    =ROOF            HEIGHT = 11        WIDTH = 136.5
                                               TILT=45
                            X=0      Y=57.5    Z=17.5   AZIMUTH = 90   ..


$   FLOOR DEFINITION

MAT-FIC-13 = MATERIAL
            RESISTANCE = 6.17 ..
```

```
$ R-FIC VALUE

SOIL-13    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-13    = LAYERS
            MATERIAL = (MAT-FIC-13,SOIL-13,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-03    =CONSTRUCTION       LAYERS=FL-1-13 ..

POLYGON-FLOOR13=  POLYGON
(0,-21.5) (0,205.6) (-15,205.6)
(-15,-21.5)   ..

FL-13     =UNDERGROUND-FLOOR
           POLYGON=   POLYGON-FLOOR13
           AREA = 500
           X=0   Y=0   Z=0
           AZIMUTH = 180
           TILT=0
           U-EFFECTIVE = 0.10
           CONSTRUCTION = FLOOR-03   ..

END  ..
COMPUTE  LOADS   ..
INPUT SYSTEMS   ..


TITLE     LINE-3 *ROCK PRAIRIE ELEMENTARY SCHOOL*
          LINE-4 *SYSTEM DEFAULT*  ..


   SYSTEMS-REPORT  SUMMARY=(SS-A,SS-C,SS-D)
                   VERIFICATION=(SV-A) ..


$ SYSTEMS SCHEDULES


FAN-1          =DAY-SCHEDULE       (1,24)(1) ..
FAN-2          =DAY-SCHEDULE       (1,24) (1)  ..


FAN-SCHED      =SCHEDULE           THRU DEC 31 (WD) FAN-1
                                               (WEH) FAN-2  ..


HEAT-1      =DAY-SCHEDULE    (1,24) (70)  ..
HEAT-2      =DAY-SCHEDULE    (1,24) (100)  ..
HEAT-3      =DAY-SCHEDULE    (1,24) (88)  ..
HEAT-4      =DAY-SCHEDULE    (1,24) (60)  ..
HEAT-5      =DAY-SCHEDULE    (1,24) (130)  ..
HEAT-6      =DAY-SCHEDULE    (1,24) (40)  ..
HEAT-7      =DAY-SCHEDULE    (1,24) (105)  ..

HEAT-WEEK1   =WEEK-SCHEDULE  (ALL)  HEAT-1    ..
HEAT-WEEK2   =WEEK-SCHEDULE  (ALL)  HEAT-2    ..
HEAT-WEEK3   =WEEK-SCHEDULE  (ALL)  HEAT-3    ..
HEAT-WEEK4   =WEEK-SCHEDULE  (ALL)  HEAT-4    ..
HEAT-WEEK5   =WEEK-SCHEDULE  (ALL)  HEAT-5    ..
HEAT-WEEK6   =WEEK-SCHEDULE  (ALL)  HEAT-6    ..
HEAT-WEEK7   =WEEK-SCHEDULE  (ALL)  HEAT-7    ..

HEAT-SCHED  =SCHEDULE        THRU FEB 28 HEAT-WEEK1
                             THRU MAR 31 HEAT-WEEK2
```

```
                              THRU MAY 31 HEAT-WEEK5
                              THRU JUN 30 HEAT-WEEK3
                              THRU AUG 31 HEAT-WEEK6
                              THRU SEP 30 HEAT-WEEK7
                              THRU OCT 31 HEAT-WEEK2
                              THRU NOV 30 HEAT-WEEK5
                              THRU DEC 31 HEAT-WEEK4  ..

COOL-1      =DAY-SCHEDULE    (1,24) (82)  ..
COOL-WEEK   =WEEK-SCHEDULE   (ALL)  COOL-1  ..
COOL-SCHED  =SCHEDULE        THRU DEC 31   COOL-WEEK   ..

$ SYSTEM DESCRIPTION $$$$$$$$$$$$

ZAIR         =ZONE-AIR      OA-CFM/PER=20  ..

CONTROL      =ZONE-CONTROL  DESIGN-HEAT-T=70
                            DESIGN-COOL-T=82
                            HEAT-TEMP-SCH= HEAT-SCHED
                            COOL-TEMP-SCH= COOL-SCHED
                            THROTTLING-RANGE=4
                            THERMOSTAT-TYPE=PROPORTIONAL ..

SPACE1-1     =ZONE
                             ZONE-AIR=ZAIR
                             SIZING-OPTION=ADJUST-LOADS
                             ZONE-CONTROL=CONTROL
                             ZONE-TYPE = CONDITIONED
                             CFM/SQFT=1 ..

SPACE1-2     =ZONE          LIKE SPACE1-1          ..
SPACE1-3     =ZONE          LIKE SPACE1-1          ..
SPACE1-4     =ZONE          LIKE SPACE1-1          ..
SPACE1-5     =ZONE          LIKE SPACE1-1          ..
SPACE1-6     =ZONE          LIKE SPACE1-1          ..
SPACE1-7     =ZONE          LIKE SPACE1-1          ..
SPACE1-8     =ZONE          LIKE SPACE1-1          ..
SPACE1-9     =ZONE          LIKE SPACE1-1          ..
SPACE1-10    =ZONE          LIKE SPACE1-1          ..
SPACE1-11    =ZONE          LIKE SPACE1-1          ..
SPACE1-12    =ZONE          LIKE SPACE1-1          ..
SPACE1-13    =ZONE          LIKE SPACE1-1          ..

PLENUM-1-1     =ZONE          ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-2     =ZONE          ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-3     =ZONE          ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-4    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-5    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80 ..
PLENUM-1-6    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-7    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-8    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-9    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-10    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
```

```
PLENUM-1-11    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..
PLENUM-1-12    =ZONE           ZONE-TYPE=PLENUM  SIZING-OPTION=ADJUST-LOADS
                            DESIGN-HEAT-T=50  DESIGN-COOL-T=80  ..


S-CONT       =SYSTEM-CONTROL  HEAT-SET-T=130
                              COOL-SET-T=60
                              COOL-CONTROL=CONSTANT
                              $COOL-RESET-SCH=SAT-RESET
                              MIN-SUPPLY-T=60
                              MAX-SUPPLY-T=130  ..

S-CONT2      =SYSTEM-CONTROL  HEAT-SET-T=130
                              COOL-SET-T=60
                              COOL-CONTROL=CONSTANT
                              $COOL-RESET-SCH=SAT-RESET
                              MIN-SUPPLY-T=60
                              MAX-SUPPLY-T=130  ..


S-FAN1        =SYSTEM-FANS    FAN-SCHEDULE=FAN-SCHED
                              FAN-CONTROL=SPEED
                              SUPPLY-STATIC=5  SUPPLY-EFF=0.85
                              RETURN-STATIC=5 RETURN-EFF=0.85
                              NIGHT-CYCLE-CTRL=STAY-OFF   ..

S-FAN2        =SYSTEM-FANS    FAN-SCHEDULE=FAN-SCHED
                              FAN-CONTROL=CONSTANT-VOLUME
                              SUPPLY-STATIC=5  SUPPLY-EFF=0.85
                              RETURN-STATIC=5 RETURN-EFF=0.85
                              NIGHT-CYCLE-CTRL=STAY-OFF
                              MAX-FAN-RATIO=1.1
                              MIN-FAN-RATIO=0.3 ..

S-TERM       =SYSTEM-TERMINAL
                              MIN-CFM-RATIO=0.2   ..


SYSTEM-1      =SYSTEM             SYSTEM-TYPE=VAVS
                                  SYSTEM-CONTROL=S-CONT
                                  SYSTEM-FANS=S-FAN1
                                  RETURN-AIR-PATH=DUCT
                                  SYSTEM-TERMINAL=S-TERM
                                  $SUPPLY-CFM=34870
                                  PLENUM-NAMES=(PLENUM-1-1,PLENUM-1-2
                                                PLENUM-1-3)
                                  ZONE-NAMES=(PLENUM-1-1,PLENUM-1-2,PLENUM-1-3,
                                              PLENUM-1-5,PLENUM-1-6,PLENUM-1-7,
                                              PLENUM-1-8,
                                              SPACE1-1,SPACE1-2,SPACE1-3,
                                              SPACE1-5,SPACE1-6,SPACE1-7,
                                              SPACE1-8) ..


SYSTEM-2      =SYSTEM             SYSTEM-TYPE=VAVS
                                  $SUPPLY-CFM=22460
                                  SYSTEM-FANS=S-FAN1
                                  SYSTEM-TERMINAL=S-TERM
                                  RETURN-AIR-PATH=DUCT
                                  PLENUM-NAMES=(PLENUM-1-4,PLENUM-1-9)
                                  ZONE-NAMES=(PLENUM-1-4,PLENUM-1-9,
                                              PLENUM-1-10,PLENUM-1-11,
                                              PLENUM-1-12,
                                              SPACE1-4,SPACE1-9,SPACE1-10,
                                              SPACE1-11,SPACE1-12) ..
```

```
SYSTEM-3      =SYSTEM             SYSTEM-TYPE=MZS
                                  $SUPPLY-CFM=6300
                                  SYSTEM-CONTROL= S-CONT2
                                  SYSTEM-FANS= S-FAN2
                                  SYSTEM-TERMINAL=S-TERM
                                  RETURN-AIR-PATH=DIRECT
                                  ZONE-NAMES=(SPACE1-13)    ..


PLANT-1 = PLANT-ASSIGNMENT  SYSTEM-NAMES=(SYSTEM-1,SYSTEM-2,SYSTEM-3)  ..


END   ..
COMPUTE SYSTEMS   ..



INPUT PLANT   ..                                     $PLANT DESCRIPTION

PLANT-REPORT
VERIFICATION  (PV-A,PV-B,PV-C,PV-E)
SUMMARY (PS-E,BEPS,BEPU)  ..

$ EQUIPMENT DESCRIPTION

$ HOT-WATER BOILER


SBOIL     =PLANT-EQUIPMENT    TYPE=HW-BOILER  SIZE=-999   INSTALLED-NUMBER=1  ..

$PLANT-PARAMETERS  HERM-REC-COND-TYPE=AIR  ..

PLANT-PARAMETERS        HCIRC-PUMP-TYPE=FIXED-SPEED
                        CCIRC-PUMP-TYPE=VARIABLE-SPEED  ..

$ AIR-COOLED RECIPROCATING CHILLER

CMPC                    =PLANT-EQUIPMENT    TYPE=HERM-CENT-CHLR  SIZE=-999
                                            INSTALLED-NUMBER=1  ..

CTOWER    =PLANT-EQUIPMENT    TYPE=COOLING-TWR  SIZE=-999 ..


PLANT-COSTS      PROJECT-LIFE=25  DISCOUNT-RATE=5 ..
ENERGY-RESOURCE  RESOURCE=ELECTRICITY  ..
ENERGY-RESOURCE  RESOURCE=NATURAL-GAS  ENERGY/UNIT=100000
                 UNIT-NAME=THERMS   ..


$------HOURLY REPORT----------------------------

SCH-1      = SCHEDULE
                       $THRU MAR 20 (ALL)(1,24)(0)
                       $THRU MAR 21 (ALL)(1,24)(1)
                       THRU DEC 31 (ALL)(1,24)(1)  ..

BG      =REPORT-BLOCK
         VARIABLE-TYPE=HERM-CENT-CHLR
         VARIABLE-LIST=(3)    ..

BG1      =REPORT-BLOCK
         VARIABLE-TYPE=GLOBAL
         VARIABLE-LIST=(1)    ..

REP1    =H-R
REPORT-SCHEDULE = SCH-1
```

```
REPORT-BLOCK=(BG,BG1)  ..

END  ..
COMPUTE PLANT   ..
STOP ..
```

SELECTED DAYLIGHTING COMMANDS AND KEYWORDS USED IN DOE-2 DAYLIGHTING SIMULATIONS

IN BUILDING-LOCATION

```
BUILDING-LOCATION  LATITUDE=30.6
                   LONGITUDE=96.22
                   ALTITUDE=610
                   TIME-ZONE=6
                   AZIMUTH=225
                   HOLIDAY=YES
                   ATM-MOISTURE=(0.7,0.7,0.7,0.7,        $DEFAULT
                                 0.7,0.7,0.7,0.7,
                                 0.7,0.7,0.7,0.7)
                   ATM-TURBIDITY=(0.1,0.1,0.11,0.12,     $FOR COLLEGE STATION
                                  0.13,0.08,0.15,0.12,   $DOE-2.1E VALUES
                                  0.11,0.09,0.08,0.07)  ..
```

IN SPACE-CONDITIONS
EXAMPLE: FIRST FLOOR SPACE 1:CLASSROOM
SKYLIGHTS

```
$ FIRST FLOOR SPACE 1

SPACE1-1       =SPACE     SPACE-CONDITIONS = CLASSROOM
                          AREA = 2640
                          VOLUME = 11880
                          DAYLIGHTING=YES
                          LIGHT-REF-POINT1 = (44,14.5,3)     $X,Y,Z CO-ORDINATES
                          LIGHT-REF-POINT2 = (73.5,14.5,3)   $X,Y,Z CO-ORDINATES
                          ZONE-FRACTION1 = 0.5
                          ZONE-FRACTION2 = 0.5
                          LIGHT-SET-POINT1 = 60              $IES RECOMMENDED VALUE
                          LIGHT-CTRL-TYPE1 = CONTINUOUS
                          LIGHT-CTRL-TYPE2 = CONTINUOUS
                          MAX-GLARE = 20                     $DOE-2 GLARE INDEX FOR
                                                             $CLASSROOMS
                          NUMBER-OF-PEOPLE = 90 ..

W-1-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 88
                           X=0    Y=0    Z=0   AZIMUTH = 180
```

```
                          INSIDE-VIS-REFL = 0.72  ..        $WALL REFLECTIVITY

W-2-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 30
                          X=88   Y=0    Z=0   AZIMUTH = 90
                          INSIDE-VIS-REFL = 0.72  ..        $WALL REFLECTIVITY
WIN1-1   =WINDOW           HEIGHT=6      WIDTH=4    Y=3   X=1 ..

W-3-1    =INTERIOR-WALL    HEIGHT = 9    WIDTH = 88
                                        NEXT-TO SPACE1-3
                                        CONSTRUCTION = SB-U
                          X=88   Y=30   Z=0   AZIMUTH = 0
                          INSIDE-VIS-REFL = (0.72,0.7)  ..   $WALL REFLECTIVITY

W-4-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 30
                          X=0    Y=30   Z=0   AZIMUTH = 270
                          INSIDE-VIS-REFL = 0.72  ..        $WALL REFLECTIVITY
WIN1-2   =WINDOW           HEIGHT=6      WIDTH=8    Y=3   X=20 ..


$ CEILING DEFINITION

POLYGON-CLNG1=  POLYGON
(0,0) (88,0) (88,30)
(0,30) ..

C1-1      =INTERIOR-WALL                  AREA=2640
                                          POLYGON=   POLYGON-CLNG1
                                          X=0   Y=0   Z=9   AZIMUTH = 180
                                          TILT=0
                                          NEXT-TO  PLENUM-1-1
                                          CONSTRUCTION=CLNG-1
                                          INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..
```

IN ROOF DEFINITION

```
POLYGON-ROOF1=  POLYGON
(0,7) (29,7) (29,0) (88,0) (88,30)
(0,30) ..

TOP-1      =ROOF
            POLYGON=   POLYGON-ROOF1
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..

WIN2-SKY   =WINDOW  HEIGHT=3   WIDTH=3   X=42.5    Y=13.12
GLASS-TYPE=WIND-2 ..                                            $SKYLIGHT DEFINITION

WIN2A-SKY   =WINDOW  HEIGHT=3   WIDTH=3   X=71.7    Y=13.12
GLASS-TYPE=WIND-2 ..                                            $SKYLIGHT DEFINITION


$ FLOOR DEFINITION

MAT-FIC-1 = MATERIAL
            RESISTANCE = 11.11 ..

$ R-FIC VALUE

SOIL-1    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
```

```
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-1     = LAYERS
            MATERIAL = (MAT-FIC-1,SOIL-1,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-1    =CONSTRUCTION       LAYERS=FL-1-1 ..

POLYGON-FLOOR1=  POLYGON
(0,0) (88,0) (88,30)
(0,30) ..

FL-1       = UNDERGROUND-FLOOR
            POLYGON=   POLYGON-FLOOR1
            AREA = 2640
            X=0   Y=0   Z=0
            AZIMUTH = 180
            TILT=0
            U-EFFECTIVE = 0.07
            CONSTRUCTION = FLOOR-1   ..
```

IN SPACE-CONDITIONS
EXAMPLE: FIRST FLOOR SPACE 1:CLASSROOM
CLERESTORIES

```
$ FIRST FLOOR SPACE 1

SPACE1-1       =SPACE     SPACE-CONDITIONS = CLASSROOM
                          AREA = 2640
                          VOLUME = 11880
                          DAYLIGHTING=YES
                          LIGHT-REF-POINT1 = (44,14.5,3)     $X,Y,Z CO-ORDINATES
                          LIGHT-REF-POINT2 = (73.5,14.5,3)   $X,Y,Z CO-ORDINATES
                          ZONE-FRACTION1 = 0.5
                          ZONE-FRACTION2 = 0.5
                          LIGHT-SET-POINT1 = 60              $IES RECOMMENDED VALUE
                          LIGHT-CTRL-TYPE1 = CONTINUOUS
                          LIGHT-CTRL-TYPE2 = CONTINUOUS
                          MAX-GLARE = 20                     $DOE-2 GLARE INDEX FOR
                                                             $CLASSROOMS
                          NUMBER-OF-PEOPLE = 90 ..

W-1-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 88
                           X=0    Y=0    Z=0   AZIMUTH = 180
                           INSIDE-VIS-REFL = 0.72  ..        $WALL REFLECTIVITY

W-2-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 30
                           X=88   Y=0    Z=0   AZIMUTH = 90
                           INSIDE-VIS-REFL = 0.72  ..        $WALL REFLECTIVITY
WIN1-1   =WINDOW           HEIGHT=6      WIDTH=4    Y=3   X=1 ..

W-3-1    =INTERIOR-WALL    HEIGHT = 9    WIDTH = 88
                                         NEXT-TO SPACE1-3
                                         CONSTRUCTION = SB-U
                           X=88   Y=30   Z=0   AZIMUTH = 0
                           INSIDE-VIS-REFL = (0.72,0.7)  ..   $WALL REFLECTIVITY

W-4-1    =EXTERIOR-WALL    HEIGHT = 9    WIDTH = 30
                           X=0    Y=30   Z=0   AZIMUTH = 270
                           INSIDE-VIS-REFL = 0.72  ..        $WALL REFLECTIVITY
```

```
WIN1-2   =WINDOW          HEIGHT=6      WIDTH=8    Y=3   X=20 ..


$ CEILING DEFINITION

POLYGON-CLNG1=  POLYGON
(0,0) (88,0) (88,30)
(0,30) ..

C1-1      =INTERIOR-WALL                    AREA=2640
                                            POLYGON=   POLYGON-CLNG1
                                            X=0   Y=0   Z=9   AZIMUTH = 180
                                            TILT=0
                                            NEXT-TO  PLENUM-1-1
                                            CONSTRUCTION=CLNG-1
                                            INT-WALL-TYPE=STANDARD ..

$ F1-1    =UNDERGROUND-FLOOR  AREA = 1458.1   CONSTRUCTION = FLOOR-0 ..
```

IN ROOF DEFINITION

```
POLYGON-ROOF1=  POLYGON
(0,7) (29,7) (29,0) (88,0) (88,30)
(0,30) ..

TOP-1      =ROOF
            POLYGON=   POLYGON-ROOF1
            X=0   Y=0   Z=13.5
            AZIMUTH = 180
            TILT=0  GND-REFLECTANCE=0
            CONSTRUCTION = ROOF-1 ..

ROOF1A=     ROOF      HEIGHT=21.7 WIDTH=59
                      AZIMUTH=0  TILT=22  X=88  Y=30  Z=13.5
                      CONS=ROOF-1  ..

ROOF1B=     ROOF      HEIGHT=8.1 WIDTH=59
                      AZIMUTH=180  TILT=90  X=29  Y=10  Z=13.5
                      CONS=ROOF-1  ..

WIN1-CLR    =WINDOW  HEIGHT=2  WIDTH=59   X=0    Y=1              $WIND-2 =DOUBLE-CLEAR
IG
GLASS-TYPE=WIND-2 ..                                              $CLERESTORY DEFINITION


$ FLOOR DEFINITION

MAT-FIC-1 = MATERIAL
            RESISTANCE = 11.11 ..

$ R-FIC VALUE

SOIL-1    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..

FL-1-1    = LAYERS
            MATERIAL = (MAT-FIC-1,SOIL-1,CC03,LT01)
            I-F-R = 0.77 ..

FLOOR-1    =CONSTRUCTION       LAYERS=FL-1-1 ..

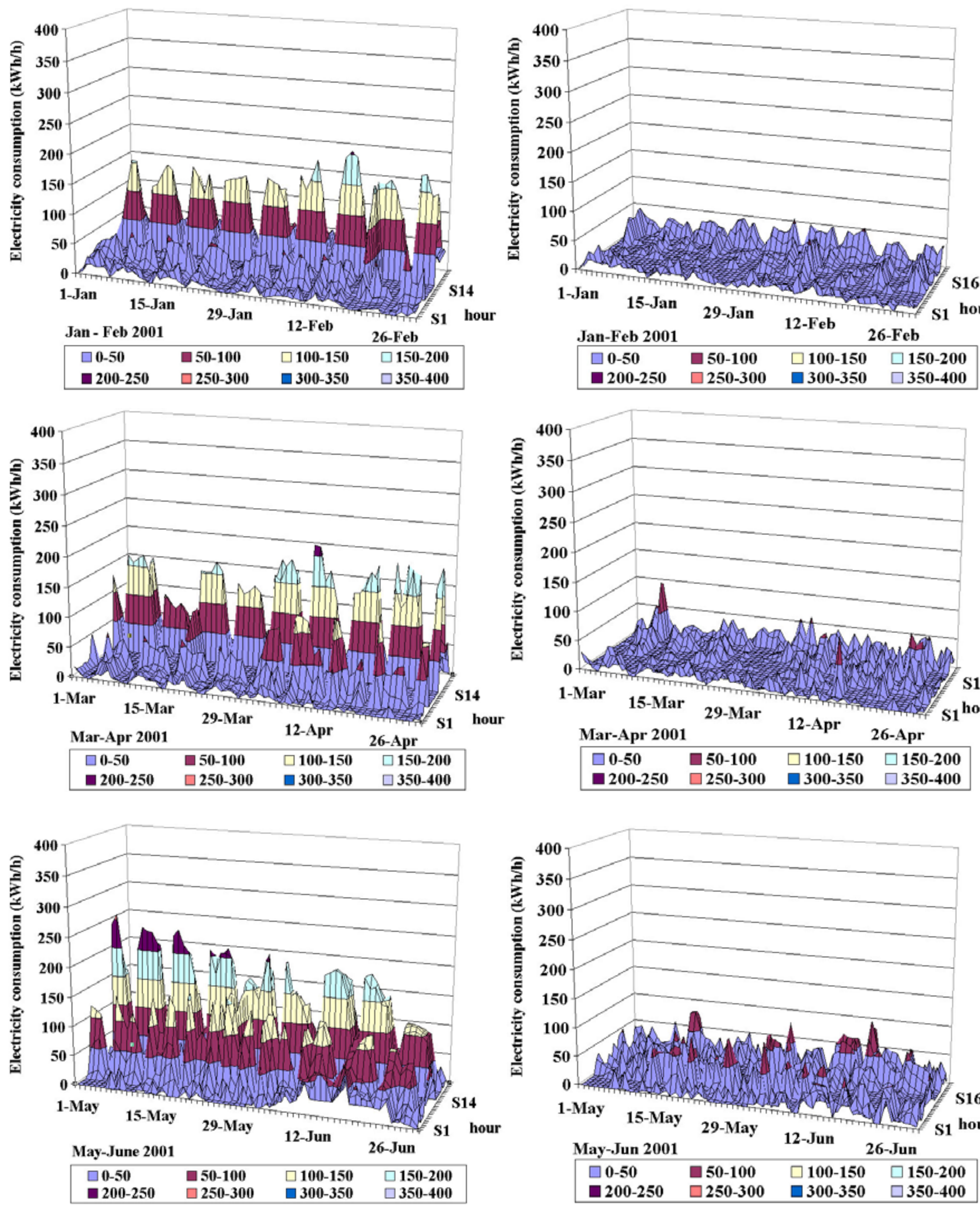
POLYGON-FLOOR1=  POLYGON
(0,0) (88,0) (88,30)
```

```
(0,30) ..

FL-1       = UNDERGROUND-FLOOR
             POLYGON=   POLYGON-FLOOR1
             AREA = 2640
             X=0   Y=0   Z=0
             AZIMUTH = 180
             TILT=0
             U-EFFECTIVE = 0.07
             CONSTRUCTION = FLOOR-1   ..
```

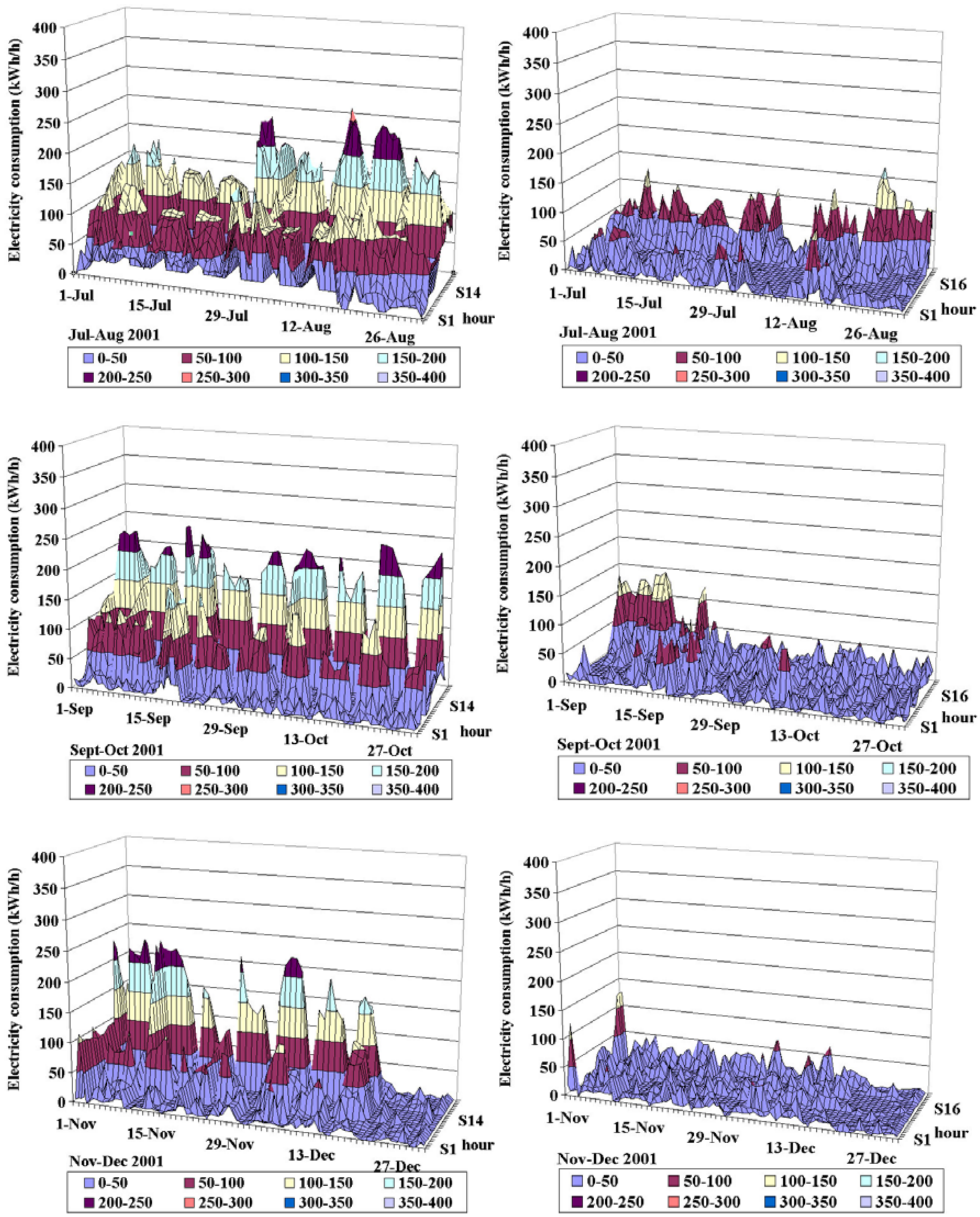
APPENDIX B

3-D SURFACE PLOTS (BI-MONTHLY) FOR THE ENTIRE YEAR USED IN DOE-2 BASE CASE HOURLY CALIBRATION



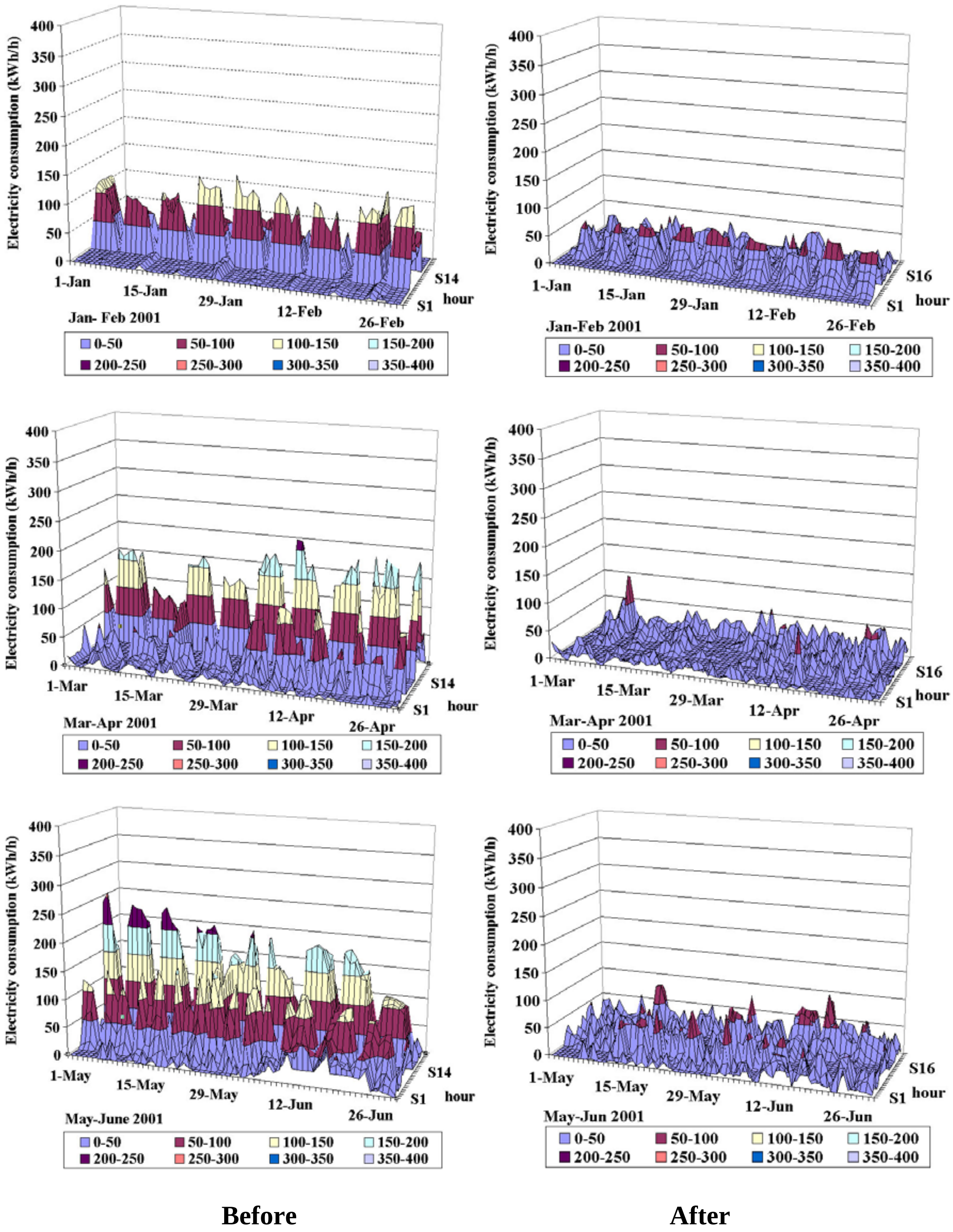
Before **After**

Measured -Simulated electricity use (Difference) before and after calibration

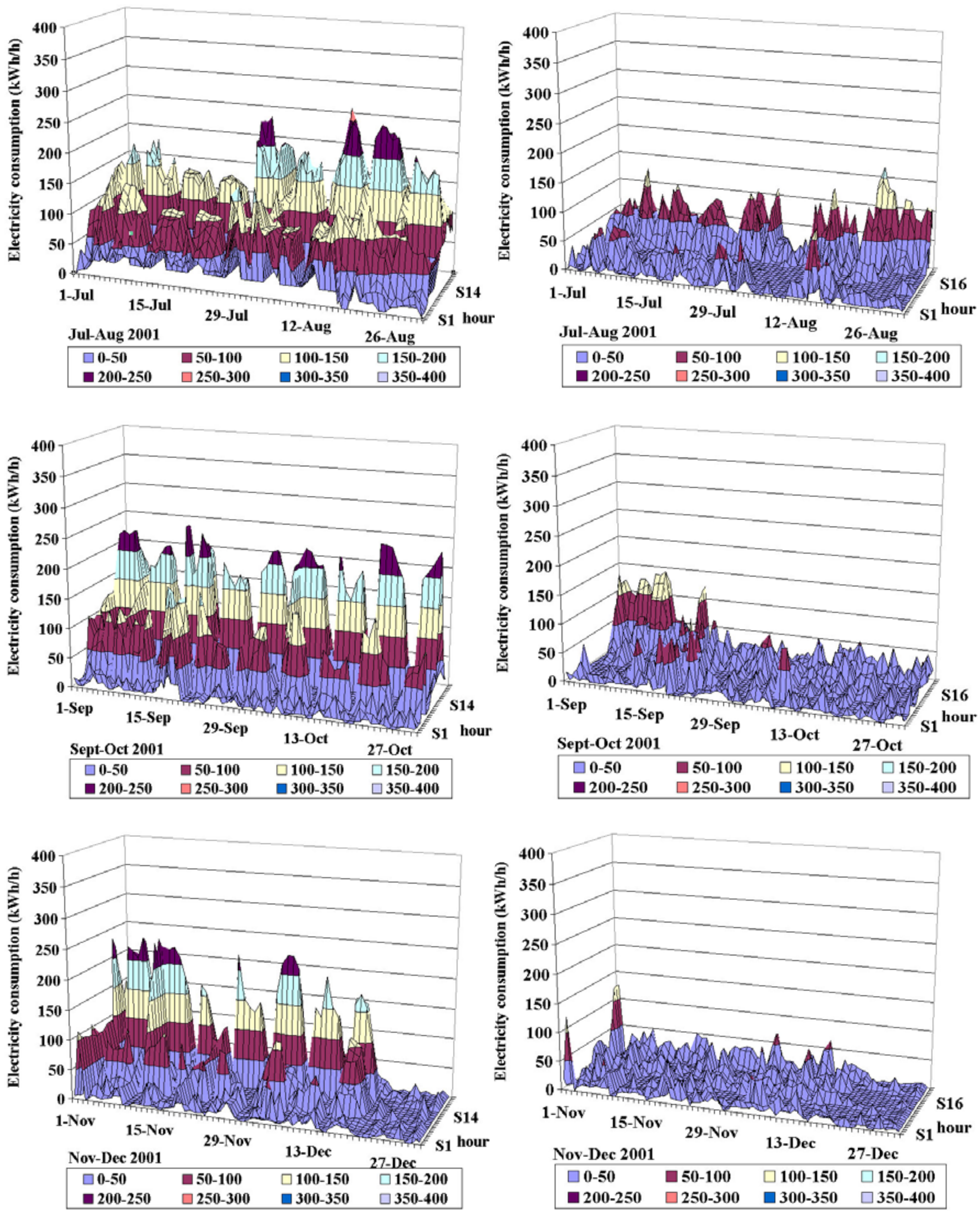


Before **After**

Measured – Simulated electricity use (Difference) before and after calibration

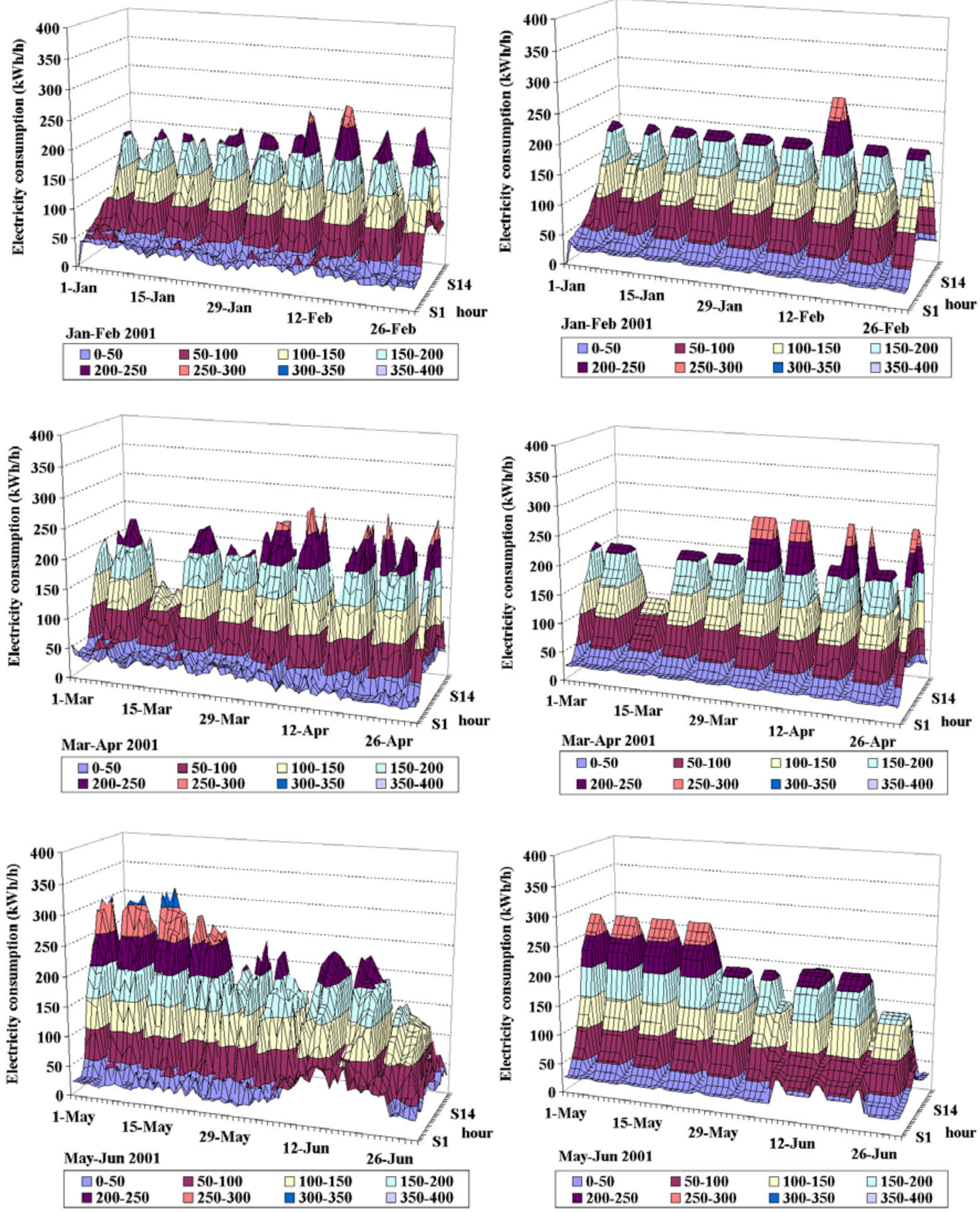


Simulated – Measured electricity use (Difference) before and after calibration



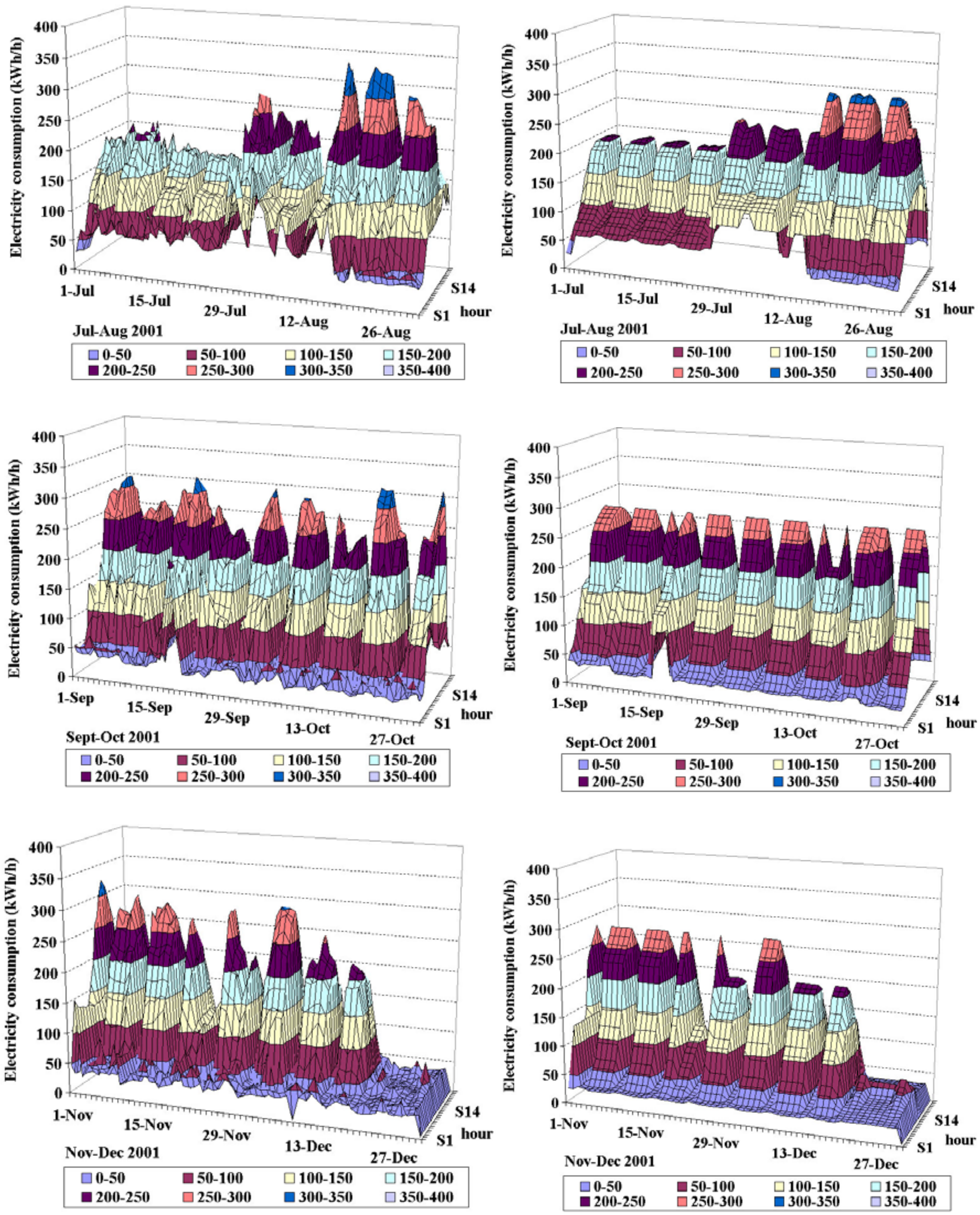
Before **After**

Simulated – Measured electricity use (Difference) before and after calibration



Measured **Simulated**

Whole building electricity use comparison between measured and simulated cases



Measured **Simulated**

Whole building electricity use comparison between measured and simulated cases

APPENDIX C

U EFFECTIVE CALCULATION METHOD USED IN CALIBRATION

As has been stated in Chapter IV, the use of the U-EFFECTIVE keyword in the UNDERGROUND-FLOOR command has been used in the calibration process in order to achieve a correct calculation of heat transfer through underground surfaces (walls and floors in contact with the ground) in DOE-2. If the raw U-value is used, then there will be over calculation of heat transfer. For this reason, an effective U-value must be specified using the U-EFFECTIVE keyword. After using the keyword, the heat transfer equation becomes:

$Q= [U\text{-}EFFECTIVE]*A\ (T_g - T_i),$

where

U is the conductance of the surface,

A is the surface area,

T_g is the ground temperature,

and T_i is the inside air temperature.

Using the calculation methodology given by Winkelmann (1998) in his study, the following example has been worked out for Space 1-1 from the DOE-2 model:

The slab in Space 1 consists of carpeted, 4 inch lightweight concrete (CC24 in the DOE-2.1e material library), with resistance=1.60 hr-ft^2-F/Btu. Using the table giving the perimeter conduction factors for concrete slab-on-grade, the F2 for this slab is equal to 0.77. The slab dimensions are 88 ft. x 30 ft., which gives a surface area of 2640 sq.ft. and a perimeter for conduction of 236 ft. The complete calculations are provided here:

Slab surface area:	A	=	88 x 30	= 2640 sq.ft.
Slab exposed perimeter:	P_{exp}	=	(2 x 88) + (2 x 30)	= 236 ft.
Effective slab resistance:	R_{eff}	=	A / (F2*P_{exp})	
		=	2640 / (0.77 x 236)	= 14.53
Effective slab U-value:	U-effective	=	1/R_{eff}	= 0.07
Actual slab resistance:	R_{us}	=	1.60+0.05+0.77	= 2.42
Resistance of fictitious layer:	R_{fic}	=	R_{eff} - R_{us} – R_{soil}	= 11.11

In the above equations, 0.77 hr-ft^2-F/Btu is considered as the average of the air film resistance for heat flow up. A 1 ft (0.3 m) layer of soil has been considered to have a resistance of 1.0 hr-ft^2-F/Btu.

The actual input in the DOE-2 input file for the Space 1 will be:

```
MAT-FIC-2 = MATERIAL
            RESISTANCE = 11.11 ..                    $ R-FIC
VALUE


SOIL-2    = MATERIAL
            THICKNESS = 1.0 CONDUCTIVITY = 1.0
            DENSITY = 115 SPECIFIC-HEAT = 0.1 ..


FL-1-2    = LAYERS
            MATERIAL = (MAT-FIC-2,SOIL-2,CC03,LT01)
            I-F-R = 0.77 ..
```

```
FLOOR-2    =CONSTRUCTION       LAYERS=FL-1-2 ..   $FLOOR


POLYGON-FLOOR2=  POLYGON
(123.5,0) (211.5,0) (211.5,30)
(123.5,30) ..


FL-2       = UNDERGROUND-FLOOR
             POLYGON=   POLYGON-FLOOR2
             AREA = 2640
             X=0   Y=0   Z=0
             AZIMUTH = 180
             TILT=0
             U-EFFECTIVE = 0.07
             CONSTRUCTION = FLOOR-2   ..
```

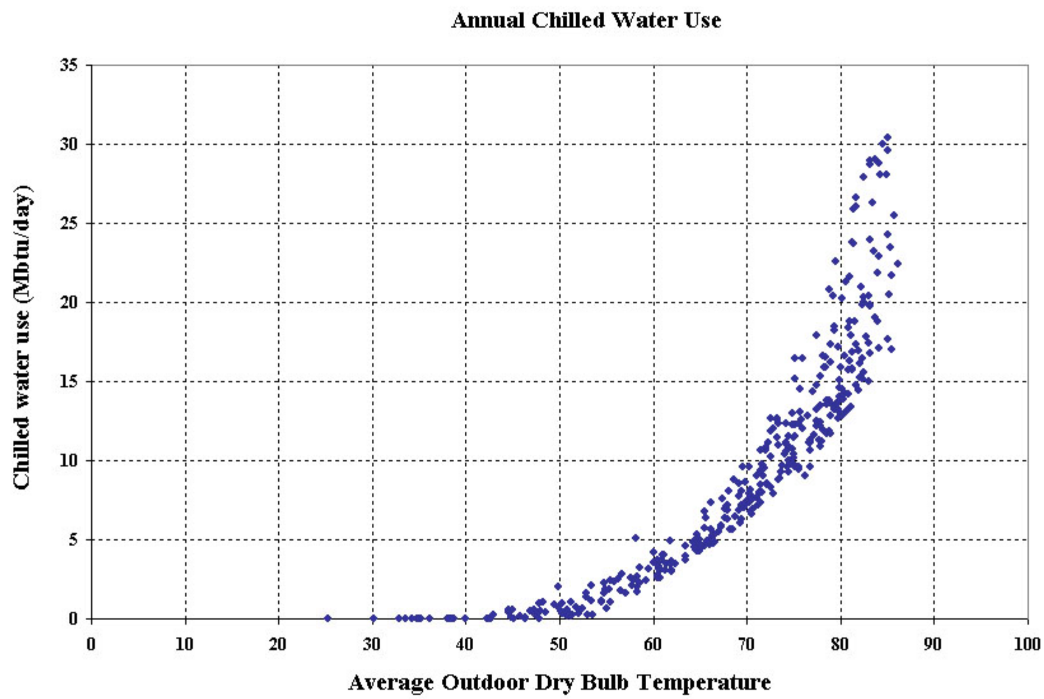
The following two tables show the calculated values for all the spaces described in the DOE-2 input file:

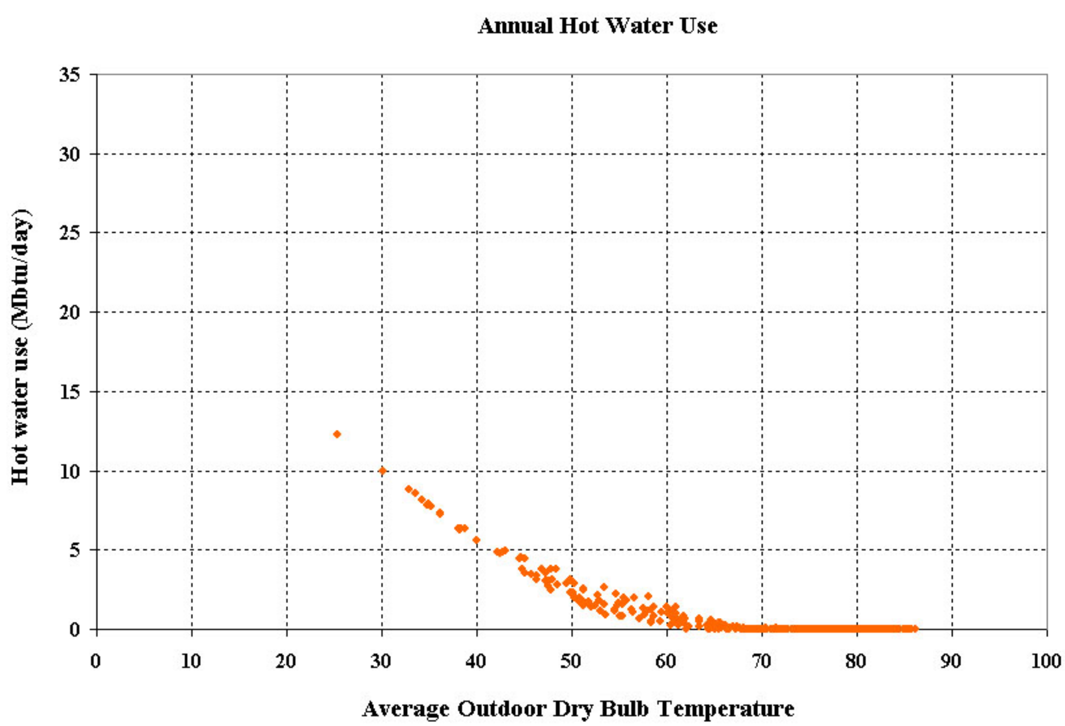
Space	**1**	**2**	**3**	**4**	**5**	**6**	**7**
F2	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Area (A)	2640	2640	13931.5	5868	2437.5	15806.5	2640
Pexp	236.00	236.00	647.00	317.00	203.00	802.00	236.00
Reff	14.53	14.53	27.96	24.04	15.59	25.60	14.53
Ueff	0.07	0.07	0.04	0.04	0.06	0.04	0.07
Rus	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Rfic	11.11	11.11	24.54	20.62	12.17	22.18	11.11

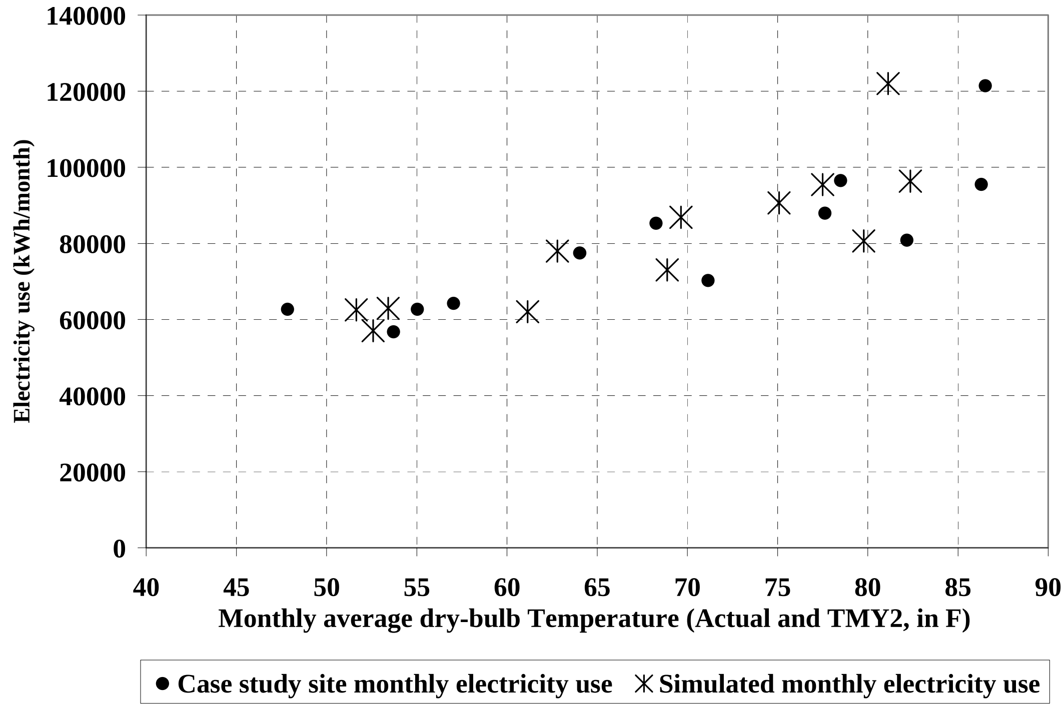
Space	**8**	**9**	**10**	**11**	**12**	**13**
F2	0.77	0.77	0.77	0.77	0.77	0.77
Area (A)	2640	8347.5	6084	1812.5	11562.5	3555
Pexp	236.00	535.00	410.00	183.00	495.00	484.00
Reff	14.53	20.26	19.27	12.86	30.34	9.54
Ueff	0.07	0.05	0.05	0.08	0.03	0.10
Rus	2.42	2.42	2.42	2.42	2.42	2.37
Rfic	11.11	16.84	15.85	9.44	26.92	6.17

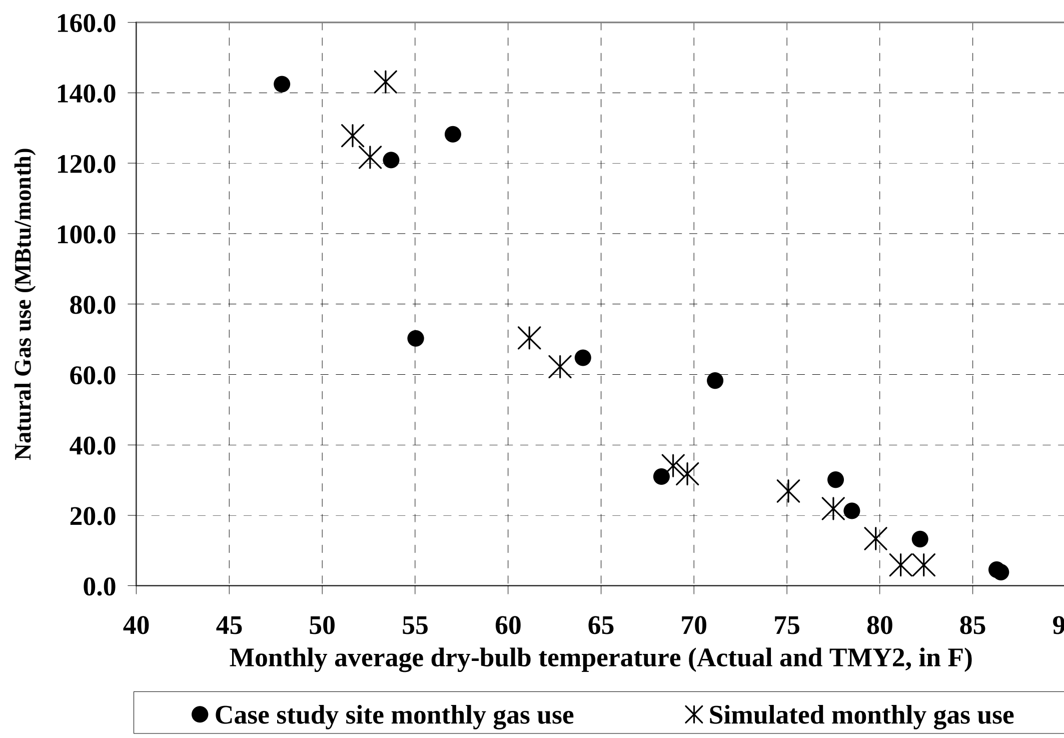
APPENDIX D

SIMULATED CHILLED AND HOT WATER USE
AND
MONTHLY ELECTRICITY AND NATURAL GAS USE CALIBRATION


Annual Chilled Water Use
Chilled water use (Mbtu/day)
Average Outdoor Dry Bulb Temperature
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100


Annual Hot Water Use
Hot water use (Mbtu/day)
Average Outdoor Dry Bulb Temperature
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100


140000
120000
100000
80000
60000
40000
20000
0
Electricity use (kWh/month)
40 45 50 55 60 65 70 75 80 85 90
Monthly average dry-bulb Temperature (Actual and TMY2, in F)
Case study site monthly electricity use
Simulated monthly electricity use


160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Natural Gas use (MBtu/month)
40 45 50 55 60 65 70 75 80 85 90
Monthly average dry-bulb temperature (Actual and TMY2, in F)
Case study site monthly gas use
Simulated monthly gas use

APPENDIX E

COPY OF APPROVAL

INSTITUTIONAL REVIEW BOARD – HUMAN SUBJECTS IN RESEARCH

TEXAS A&M UNIVERSITY

Office of the Vice President for Research

Date May 4, 2004

MEMORANDUM

TO:	Umesh Vinayak Atre Architecture MS 3137
FROM:	Dr. E. Murl Bailey, CIP, Advisor Institutional Review Board MS 1112
SUBJECT:	IRB Protocol Review

Title: "Energy Reduction in Elementary Schools through Daylighting"

Protocol Number: 2004-0249
Review Category: Exempt from Full Review
Approval Date: May 4, 2004 **to** May 3, 2005

The approval determination was based on the following Code of Federal Regulations
http://ohrp.osophs.dhhs.gov/humansubjects/guidance/45cfr46.htm

______ **46.101(b)(1)**	______ **46.101(b)(4)**
✓ **46.101(b)(2)**	______ **46.101(b)(5)**
______ **46.101(b)(3)**	______ **46.101(b)(6)**

Remarks:

The Institutional Review Board – Human Subjects in Research, Texas A&M University has reviewed and approved the above referenced protocol. Your study has been approved for one year. As the principal investigator of this study, you assume the following responsibilities:

***Renewal*:** Your protocol must be re-approved each year in order to continue the research. You must also complete the proper renewal forms in order to continue the study after the initial approval period.

***Adverse events*:** Any adverse events or reactions must be reported to the IRB immediately.

***Amendments*:** Any changes to the protocol, such as procedures, consent/assent forms, addition of subjects, or study design must be reported to and approved by the IRB.

***Informed Consent/Assent*:** All subjects should be given a copy of the consent document approved by the IRB for use in your study.

***Completion*:** When the study is complete, you must notify the IRB office and complete the required forms.

Page 1 of 2

Office of Research Compliance

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Texas A&M University

1112 TAMU
318 Administration Building
College Station, Texas
77843-1112

979.845.8585
FAX 979.862.3176

PART 46.101 PROTECTION OF HUMAN SUBJECTS

46.101

(a) Except as provided in paragraph (b) of this section, this policy applies to all research involving human subjects conducted, supported or otherwise subject to regulation by any Federal Department or Agency which takes appropriate administrative action to make the policy applicable to such research. This includes research conducted by Federal civilian employees or military personnel, except that each Department or Agency head may adopt such procedural modifications as may be appropriate from an administrative standpoint. It also includes research conducted, supported, or otherwise subject to regulation by the Federal Government outside the United States.

(1) Research that is conducted or supported by a Federal Department or Agency, whether or not it is regulated as defined in 46.102(e), must comply with all sections of this policy.

(2) Research that is neither conducted nor supported by a Federal Department or Agency but is subject to regulation as defined in 46.102(e) must be reviewed and approved, in compliance with 46.101, 46.102, and 46.107 through 46.117 of this policy, by an Institutional Review Board (IRB) thatoperates in accordance with the pertinent requirements of this policy.

(b) Unless otherwise required by Department or Agency heads, research activities in which the only involvement of human subjects will be in one or more of the following categories are exempt from this policy:[1]

(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

(3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if:
(i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) Federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

(5) Research and demonstration projects which are conducted by or subject to the approval of Department or Agency heads, and which are designed to study, evaluate, or otherwise examine:
(i) Public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

(6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food isconsumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

VITA

Name:	Umesh Vinayak Atre
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Education:	Bachelor of Architecture (B. Arch) *April 1999* *Sir J. J. College of Architecture, Mumbai, India*
	Master of Science in Architecture (M. S. Arch) *May 2005* *Texas A&M University, College Station, USA*
Research Interests:	Daylighting in buildings Building energy simulation Energy-efficient school design